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Abstract

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J.R. Butler

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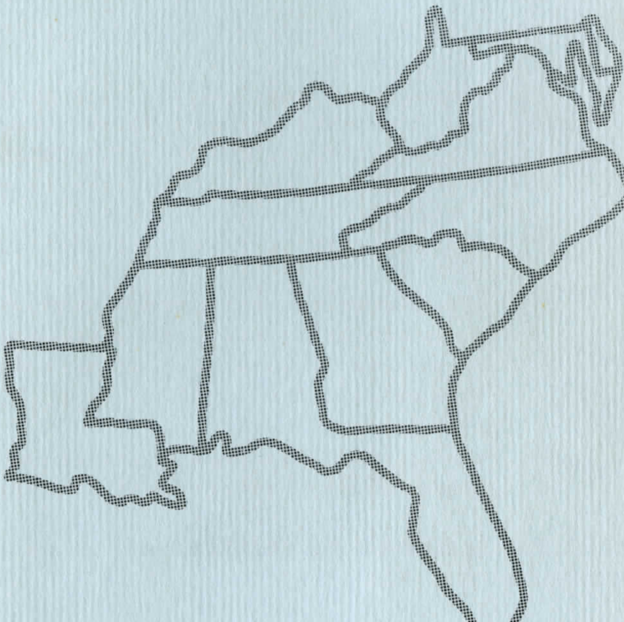

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A PROPOSAL FOR COORDINATING GEOLOGICAL RESEARCH IN THE SOUTHEAST

By

James W. Clarke
McLean, Virginia

S. Duncan Heron, Jr.
William J. Furbish
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and

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Arlington, Virginia

Geological publications have long been an adequate means of disseminating the results of geological research. This method of mass communication between geologists, however, is concerned largely with projects that have been completed. No mechanism is now in existence on a regional scale whereby the planning and development of a research program can be coordinated systematically with other related research.

The advantages of coordination in planning a research program are many. One of the most important would be the facility by which parallel projects could be conceived. A geologist mapping a quadrangle in South Carolina might make a collection of geologic samples which would be used simultaneously by others for the purposes of age determination, spectrographic analysis or petrography. The geochemist who is interested in trace elements in diabase could well use a listing of the location of each project in the Appalachian Piedmont.

As a beginning to a program for offering the opportunity to geologists of the Southeast to coordinate the planning of their research, inquiries are being sent to geologists who are known to us to have projects in this region. A copy of the inquiry is included as the last page of this issue of Southeastern Geology. This page is not numbered; it can be removed and sent in to register a project. Anyone inadvertently omitted from this mailing is invited to submit information on his project to:

Research Directory
Geology Department, Duke University
Box 6665, College Station
Durham, North Carolina 27708

The project titles submitted by November 1, 1968, will be compiled alphabetically by author and indexed according to the system used to index the Bibliography of North American Geology. This listing is to be published by Southeastern Geology as "Directory of Geological Research in the Southeast."

The permanent file for the Directory will be housed at Duke University. After the first edition has been published, a firm decision can be made as to the next step in developing the means for systematic coordination. Perhaps the next stage should be the publication of a short description of the purposes of each project. Suggestions on this subject would be appreciated.

The program outlined here is not the domain of the authors or of just a small interested group; rather, it is a program that belongs to every geologist working in the Southeast. Each is in effect a coauthor and shares in the responsibility of its success. Our program can be far reaching both in serving ourselves and as a model for others. Cooperation from everyone is vital.

STRUCTURE OF EASTERNMOST NORTH CAROLINA PIEDMONT

By

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ABSTRACT

A structural geologic map based on reconnaissance and scattered published data is presented that covers some 4,000 square miles in eastern Piedmont North Carolina, east of the Deep River Triassic basin. The region is a great anticlinorium that plunges southward. The axial area is occupied by granitic plutons surrounded by zones of high-rank metamorphic rocks ranging up to kyanite grade. These in turn are flanked by low-rank metasedimentary and metavolcanic rocks of the graywacke suite, of Paleozoic or perhaps late Precambrian age. Foliation in most rocks parallels the compositional layers. Granitic bodies also occur along both the eastern and western belts of low-rank rocks, and a swarm of ultramafic lenses lies in the high-grade rocks west of the central pluton. Several anticlines and synclines are located in the low-rank and high-rank rocks on the flanks of the major anticlinorium and other unidentified isoclinal folds must exist.

INTRODUCTION

The Piedmont province in northeastern North Carolina - and in the adjacent part of Virginia - extends farther eastward across strike of the crystalline rocks than anywhere else south of New England. Structures exposed here are covered along their extensions to the northeast and the southwest by greater overlap westward of the Coastal Plain sediments. This area is a broad bulge of the basement rocks that brings up to view some forty miles additional width of this complex metamorphic and igneous region.

The area chosen for this report lies in North Carolina east of the down-faulted Deep River basin of Triassic sediments, and is bounded on the east and south by overlapping Cretaceous and Cenozoic sediments. It is roughly 50 miles wide east-west and 80 miles long. Relief is low, soil deep, and outcrops sparse. Most uplands are covered with a few feet of surficial alluvium, so that observation of bed rock is nearly restricted to man-made excavations and to narrow belts along streams.

Reconnaissance investigation of this area was undertaken chiefly to provide better understanding of the regional bed rock structure as background for detailed mapping of the Raleigh, North Carolina, 15-minute quadrangle and its adjacent areas. The generalized distribution of major rock types was presented by the Geologic Map of North Carolina (1958) but published structural data in this area have been scanty indeed. Only features of pre-Triassic age are treated.

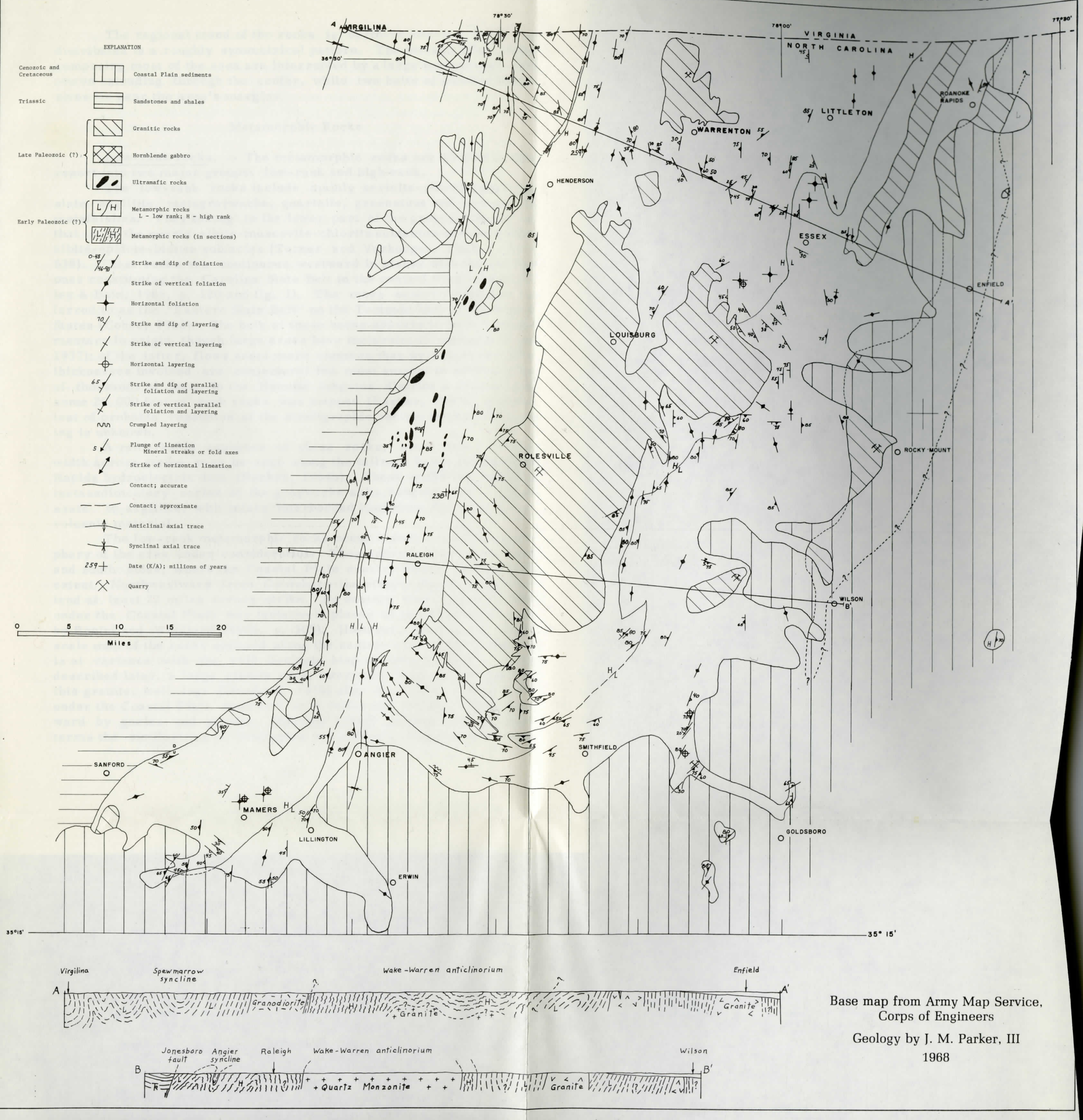
Published and manuscript data have been compiled, especially from state and federal reports on ground water and on mineral deposits, and from theses of graduate students at North Carolina State University. Publications that were used are listed in the bibliography. Detailed information is in hand from the author's work in the Hamme tungsten district (Parker, 1963) and in the vicinity of Raleigh (not yet published). Experience with other parts of the area resulted in part from field work in 1956 for the N. C. Department of Conservation and Development contributing to the 1958 Geologic Map of North Carolina, and from a project, financed by the National Science Foundation, in 1963 and 1964, to prepare guide books for geologic field trips for eight counties in the area. Rapid reconnaissance of other portions was carried on intermittently during the winter of 1962-1963, and on many later occasions, chiefly to determine the structural attitudes of the rocks. Some few parts have hardly been visited. The completeness and reliability of information thus vary greatly from place to place, and conclusions are necessarily tentative. A preliminary report was presented at the meeting of the Southeastern Section of the Geological Society of America in April, 1963 (Parker, 1964a). The purpose of this paper is to report the existing state of information on the region, thus also making evident the many opportunities for detailed studies of unsettled problems.

Reading of this report may be facilitated by referring to the 1958 Geologic Map of North Carolina which will supply additional information on regional setting and geographic locations.

DISTRIBUTION OF ROCKS

General Statement

The area is underlain chiefly by a wide variety of metamorphic rocks derived from both sedimentary and igneous rocks that have been altered to varying metamorphic grades. Enclosed in them are one large and many smaller granitic plutons, and numerous small mafic intrusives. The major lithologic boundaries shown on the accompanying map (Figure 1) are in part taken from the Geologic Map of North Carolina (North Carolina Div. Mineral Resources, 1958) though they have been revised here and there in the light of more recent information; metamorphic rock units particularly have been treated differently. The limit of the Coastal Plain sediments has been greatly generalized and all outliers omitted in order to facilitate consideration of the older rocks.



Base map from Army Map Service, Corps of Engineers

Geology by J. M. Parker, III
1968

The regional trend of the rocks is north-northeast. They are distributed in a roughly symmetrical pattern. The metamorphic rocks composing most of the area are interrupted by a large irregular granitic pluton extending through the center, while two belts of smaller intrusives lie near the area's margins.

Metamorphic Rocks

Low-rank rocks. -- The metamorphic rocks are divided in this report into two major groups: low-rank and high-rank.

The low-rank rocks include mainly sericite-chlorite phyllite, slate, argillite, metagraywacke, quartzite, greenstone and comparable metafelsites. They belong to the lower part of the greenschist facies; that is, to the quartz-albite-muscovite-chlorite subfacies and the quartz-albite-epidote-biotite subfacies (Turner and Verhoogen, 1960, p. 531-538). These rocks are continuous westward in places with the similar ones constituting the Carolina Slate Belt in the central Piedmont (Conley & Bain, 1965, p. 120 and fig. 1). The more easterly ones are referred to as the "Eastern Slate Belt" on the Tectonic Map of the United States (Cohee, 1962). The bulk of these rocks appears to be metasedimentary in origin, though large areas have metavolcanic types (Stuckey, 1937); of the latter, flows seem more common than pyroclastics. The thicknesses involved are conjectural but must amount to several tens of thousands of feet. In the Hamme tungsten district a thickness of some 20,000 feet of such rocks was mapped (Parker, 1963). The extent of probable repetition of the stratigraphic section by isoclinal folding is unknown.

A remarkable exposure of these rocks, more than a mile in width across strike, may be seen along the tailrace below the Roanoke Rapids hydroelectric dam (Parker, 1964b). These rocks are mostly a metasedimentary series of the graywacke suite, ranging from conglomerate to argillite, with minor interbedded limestone and some metavolcanic material.

The low-rank metamorphic rocks occur chiefly around the periphery of the area under consideration. They underlie most of the east and south sides, where the Coastal Plain overlap blanks out their full extent. Northwestward from Goldsboro the steeply dipping slates extend at least 22 miles across strike. An eastern limit of these rocks under the Coastal Plain was tentatively placed on geophysical grounds by Bonini and Woollard (1960, p. 305). However, their very small scale map of the rocks exposed along the eastern edge of the Piedmont is at variance with the 1958 Geologic Map of North Carolina. As is described later, a large granite mass intervenes here. To the east of this granite, well logs (Mundorff, 1946) show that slates continue out under the Coastal Plain another 7 or 8 miles and are succeeded eastward by gneiss and granite. Dietrich (1960) pointed out in general terms the similarities in lithologies and probable ages and structures of the basement rocks beneath the Coastal Plain to those exposed in the adjacent eastern Piedmont.

To the south, also, low-rank rocks extend as much as 25 miles out beneath the Coastal Plain sediments. Slates are reported in water wells throughout southern Johnston and Harnett Counties and most of Cumberland County (Pusey, 1960; Schipf, 1961, 1964).

The low-rank rocks also form a narrow, discontinuous strip on the west side of the mapped area next to the Triassic graben, which is down-faulted into these rocks. They are bordered toward the center of the area by higher rank rocks and are interrupted by numerous granitic intrusives.

High-rank rocks. -- The high-rank metamorphic rocks include biotite-muscovite gneiss and schist chiefly, commonly with some interbedded hornblende gneiss, and in places minor amounts of quartzite; no limestone or marble is known. They belong to the upper greenschist facies and the amphibolite facies, having almandine and associated minerals (Turner and Verhoogen, 1960, p. 539-541 and 544-548). Most of them were derived from sedimentary rocks, though some hornblendic rocks may have been mafic tuffs, sills, and dikes (Dickey, 1963, p. 24; Fortson, 1958, p. 30 and 40).

The high-rank rocks form sheaths around the major granitic plutons or surround several smaller ones (Figure 1). They occur most widely along the west side of the large central granitic pluton (the Rolesville granite) and in a broad area to the northeast. West of Raleigh a progression of metamorphic zones may be traced from chloritic rocks eastward into rocks having in succession biotite, garnet, kyanite and staurolite (Fortson, 1958, p. 88-89; Broadhurst and Parker, 1959, p. 3-5). Gneisses and schists near the Rolesville granite and the subsidiary intrusives to the north are abundantly injected by pegmatites up to 50 feet or even more in width. These are especially numerous in a belt 3 to 4 miles wide along the west side of the Rolesville granite and in a wide area to the northeast in Warren and Franklin counties (Steel, 1952).

High-rank rocks also form much narrower belts along the eastern and southern margins of the Rolesville granite and occur widely in the southwestern part of the mapped area. The high-rank rocks west of the Rolesville granite extend northward across Virginia and were earlier correlated with the Wissahickon Formation (Jonas, 1932; Stose and Ljungstedt, 1932).

Far out in the Coastal Plain some 16 miles east of Wilson, a unique monadnock on the basement brings to the surface coarse-grained biotite gneiss. Similar rocks are reported (Mundorff, 1946) in various wells along this belt. High-rank metamorphic and igneous rocks with isotopic ages ranging from Late Precambrian to Middle Permian are reported by Denison et al (1967) in six cores taken from the outer North Carolina Coastal Plain basement.

Boundary between low-rank and high-rank rocks. --The boundary drawn between low and high rank rocks (Figure 1), is intended to separate rocks containing chlorite, epidote, and biotite from those containing almandine and higher temperature minerals. Difficulty in making these mineralogical distinctions results from deep weathering of most outcrops. In practice, the aphanitic types whether massive or with cleavage were designated low-rank, while rocks consisting of conspicuous flakes of muscovite and biotite, or of hornblende needles, whether clearly garnetiferous or not, were put in the higher rank group. Thus, the true garnet isograde probably in places lies somewhat inside the areas shown as high-rank.

In most parts of the area the metamorphic boundary parallels the local trend of foliation and layering. Zig-zags in the line reflect interfingering of metamorphic types. Some of these loops may be due to field errors and others to interlayering of rocks having different metamorphic susceptibilities, or perhaps to later deformation. In the region as a whole the boundary shows a strong correlation with the Rolesville granite and related plutons to the north. They are surrounded exclusively by higher rank rocks.

This metamorphic boundary cuts obliquely across foliation and layering in two principal areas. East and southeast of Louisburg the boundary runs sharply across the structure, and the granite there disrupts it for a distance of nine miles. Likewise, in the southwestern corner of the region the boundary turns sharply across the foliation near the places where it passes beneath younger formations.

Intrusive Rocks

Granitic plutons. -- Granitic rocks ranging from granite to granodiorite are exposed in a central and two marginal belts in the region (Figure 1). No detailed study of these rocks has been made, though for many localities where they have been quarried, petrographic descriptions are available in reports by Watson and Laney (1906) and by Councill (1954).

The center of the area under consideration is occupied by a large irregular granitic mass about 50 miles long and ranging in width from 10 to 15 miles for much of this distance (Figure 1); the broad protrusion east of Louisburg is discussed separately below. The eastern and western contacts of the main granite body are relatively smooth and parallel to the foliation of the gneisses and schists that form the wall rocks. At the northern and southern ends, however, the contacts are notably irregular, with many sill-like extensions penetrating the contorted metamorphic rocks. For convenience of reference, this body has been called the "Rolesville granite" pluton (Stuckey, 1965, p. 115) named for the town in Wake County near which the largest quarry in the state has been developed in this rock. The petrologic character of this pluton ranges at least from biotite granite to biotite quartz monzonite. Most thin sections observed by the writer have about as much plagioclase (oligoclase) as potassium feldspar (largely microcline). At the Lassiter quarry near Rolesville two contrasting kinds of rock occur in about equal amounts. An earlier finer grained, medium dark, quartz monzonite (?) has been invaded by a coarser granite (?) with less biotite. Biotite-rich schlieren and uniform dark layers are abundant near the contacts of this pluton but some foliated rock is also encountered near its center. Pegmatite and aplite dikes, and dikes comprising both these rock types, are numerous in the pluton and in the wall rocks. The Rolesville granite pluton corresponds in position with a strong negative (-35 milligals) Bouguer gravity anomaly (Mann, 1962, p. 214).

The two small stocks near Warrenton, northeast of the Rolesville pluton (Figure 1), are petrographically similar to the main body, and also lie along a negative (-10 milligals) anomaly (Mann, 1962, p. 214). Presumably they are bosses on the same large intrusive. Reconnaissance indicates the probable existence of additional small granitic bodies in this area.

East of Louisburg is a granite mass some ten miles in diameter that is mapped as narrowly connected with the Rolesville granite. This connecting area, however, includes numerous large north-trending bands of gneiss that amount to perhaps a third of the interval, so it is likely that detailed mapping here will show this to be a separate pluton. The rock is very low in dark minerals. Its contacts in most places cut sharply across the foliation and layering of the wall rocks. Furthermore, it breaks abruptly across the boundary between high-rank and low-rank rocks giving the appearance of post-dating the regional metamorphism. Along its eastern contact chloritic phyllite and argillite may be observed within a hundred feet of the contact. This pluton resembles those along the eastern edge of the area more than it does the Rolesville granite.

The western belt includes one large and half a dozen small plutonic bodies. The elongate pluton lying northwest of Henderson, in the Hamme tungsten district, and which extends northeastward beyond the state line, is an odd albite granodiorite lying in a belt of low-rank rocks. The rock consists of about 25 percent quartz (much of which is blue), 20 percent microcline, 50 percent plagioclase (about Ab_{90}) with some 5 percent biotite, chlorite, epidote, and accessory minerals. Plagioclase is invariably crowded with tiny sericite and epidote inclusions, though the rims are relatively clear. This body is regarded as the result of granitization (Parker, 1963, p. G 24-G 38). It lies on the west flank of the negative anomaly corresponding to the Rolesville pluton and has values ranging from 0 to +10 milligals (Mann, 1962, p. 214). Its character is thus quite different from the granite and quartz monzonite intrusives to the east and southeast.

Farther southwest along the western side of the map area, near the Triassic rocks, are several small intrusives. The small oval body about 12 miles south-southwest of Henderson is coarse-grained, pink (microcline) granite, similar to rocks in the eastern belt near Wilson.

The other bodies are quite mafic and variable. They have not been studied in detail, but some appear to be closely similar to the albite granodiorite of the Hamme tungsten district.

Along the eastern edge of the Piedmont between Wilson and Roanoke Rapids is a series of granite exposures along the larger streams. These are likely to be parts of a very large pluton which is mostly covered by Coastal Plain sediments. Widths of as much as 5 to 6 miles of granite are exposed along the streams near Rocky Mount, and some water wells five miles farther eastward in the Coastal Plain are reported (Mundorff, 1946, p. 50-57 and 68-75) to bottom in granite. A conjectural eastern contact based on well data is shown on the map (Figure 1). This granite seems to be distinctly different than the Rolesville pluton. The relatively scanty information available (Watson and Laney, 1906, p. 20-27; Councill, 1954, p. 10-12; and personal observation) indicates that the rock is exceedingly variable in grain size and biotite content even in one quarry. Coarse-grained red microcline granite with but little plagioclase and biotite is common in this belt though perhaps not predominant. Pegmatite and aplite dikes seem to be relatively scarce. A gravity low (-30 milligals) corresponds with the Rocky Mount part of this belt (Mann, 1962, p. 213) but it trends north-northwest, oblique to the granite.

The oval stock about 10 miles west of Wilson, in which the large Neverson quarry is developed (Councill, 1954, p. 10-11), is also rich in potash feldspar though the rock is gray and fairly mafic.

The narrow granite strip shown west of Roanoke Rapids and extending 25 miles south-southwest from the state boundary is very poorly exposed. Mapping in greater detail will almost certainly show it to consist of scattered small bodies. The south end is medium grained, pink granite (Goedicke, 1948, p. 11) that sharply cross-cuts the foliation of phyllites.

Mafic and ultramafic rocks.-- Various mafic and ultramafic rock bodies occur near the western side of the region (Figure 1). They include hornblende gabbro, hornblendite, serpentinite, soapstone, and other altered types. The regional location of most of these has been shown by Larrabee (1966, sheet 2).

At the northwest corner of the map area are two bodies of hornblende gabbro, one of which extends northward into Virginia (Parker, 1963, p. G 22-G 24). The round body lies along the axis of the Spewmarrow syncline, referred to later; it includes some granitic rock. These rocks are coarse-grained and in part ultramafic. Both bodies lie in a belt of low-rank, metavolcanic rocks.

A swarm of about two dozen lenticular bodies of serpentinite, soapstone, and other altered ultramafic rocks lies about midway between Raleigh and Henderson. The group extends north-northeastward over an area about 20 miles long, being 4-5 miles wide at its southern end and seemingly narrowing to a point at the north. The apparent gap in the middle of the belt may not be real, as little mapping has been done there. Individual lenses range in outcrop length from a few hundred feet to about three miles. All are poorly exposed and are known chiefly from float. These lenses lie in a belt of high-rank mica and hornblende gneisses and schists characterized by garnet and kyanite. They are conformable to the local and regional foliation in their position but the few actual exposures of their contacts are so deformed that original relations are uncertain. Primary olivine and pyroxene remain now only as rare relics, and the rocks consist chiefly of variable proportions of serpentine, amphiboles, talc, and chlorite. Details regarding some of these lenses are reported by Dickey (1963); Farquhar (1952), and George (1939). This belt with ultramafic lenses has gravity values between 0 and +5 milligals (Mann, 1962 pl. 1) and lies on a gradient between a negative low to the east and a positive high to the west. Evidently no large ultramafic body exists at high levels in the crust along this belt.

AGES OF THE ROCKS

The metamorphic rocks in the eastern North Carolina Piedmont are now generally regarded as early to middle Paleozoic in age, though some authors still class the gneisses and schists as Precambrian(?). The intrusives appear likely to be of middle to late Paleozoic age.

A definite Cambrian age for argillite from the Carolina Slate Belt, some 100 miles west of the area of this report, has recently been assigned on paleontologic evidence by St. Jean (1964, p. 307). In addition, lead-alpha measurements on zircon crystals from tuff in the same belt (White et al., 1963, p. C 107-C 109) indicate an Ordovician age (440 ± 60 and $\overline{470 \pm 60}$ m.y.). These rocks are physically continuous and of similar lithology with the low-rank rocks of the easternmost Piedmont in North Carolina, thus strongly suggesting that all are likely to have been deposited during the same era. The Tectonic Map of the U.S. (Cohee, 1962) also indicates Paleozoic age for the "Eastern Slate Belt."

Agreement is lacking, however, on the relation of the high-rank rocks to the Slate Belt rocks. In the author's experience in detailed mapping north of Henderson (Parker, 1963, p. G 10-G 12) and west of Raleigh (Fortson, 1958, p. 7-8 and pl. III), one group grades into the other by variation in metamorphism. Because of the regular homoclinal dip westward in both these areas, the higher rank rocks appear to be stratigraphically beneath the low-rank rocks. No sign of an unconformity between them was observed. It must be admitted that a disconformity or even an angular unconformity might have existed originally that later was obliterated by deformation. The parallel positions and gradational relations of all the rocks, however, lead the author to regard them as having formed during one depositional period, probably during early Paleozoic time, though possibly starting in the late Precambrian. Stuckey (1965, p. 28-29 and 91-93) and Bain (1966, p. 11

and pl. 2), on the other hand, regard the two rock groups as of greatly different ages and imply that Precambrian gneisses and schists are unconformably overlain by Slate Belt rocks.

Two age determinations (potassium-argon ratios) have been made (Kulp and Eckelmann, 1961, p. 409) on biotite from gneisses in the high-rank belt west of the Rolesville granitic pluton. At the Gresham's Lake quarry eight miles north-northeast of Raleigh (Figure 1) an age of 238 m.y. was obtained, and at the Greystone quarry four miles northeast of Henderson an age of 259 m.y. The first of these localities is about a mile west of the Rolesville granite and the second is about five miles north of its north end, both in gneisses abundantly injected by pegmatite. Because of the close relations of the high-rank rocks and the Rolesville granite, previously described, the ages determined for mica in the gneisses must also apply to the adjacent granite. These dates, then, indicate a time of regional dynamic metamorphism and crustal heating in the late Devonian or early Mississippian periods (Holmes time scale) or in the Permian period (Kulp scale). The rocks recrystallized at this time might have been accumulated during either early Paleozoic or perhaps even Precambrian time.

Conglomerates in the upper Triassic sediments along the west side of the area under consideration contain abundant pebbles of the various metamorphic and igneous rocks of the region, thus setting an upper limit on the age of the latter.

STRUCTURAL FEATURES

Foliation

Most of the metamorphic rocks have well developed cleavage or foliation resulting from parallel alignment of inequidimensional minerals.

In the low-rank argillites, slates, phyllites, and quartzites, sedimentary bedding is commonly distinct. At most localities the recrystallized, secondary minerals have formed with longer dimensions parallel to the layering, so that the rocks possess good bedding cleavage. This condition is shown on Figure 1 by a strike symbol having both bedding and foliation dip indicators. At a relatively small number of places, however, secondary cleavage oblique to bedding was observed; this is presumed to be axial plane cleavage. Such relations were recorded chiefly along the southern side of the map area, in the stretch between Goldsboro and the vicinity of Lillington. These are shown in Figure 1 by pairs of closely spaced bedding and foliation symbols. Such observations have been too sparse to be of much help in locating fold axes. The metavolcanic rocks are commonly more massive and some have little or no cleavage. Some show distinct lamination resulting from bedding in metatuffs and from flow layers in lava sheets.

The coarser grained gneisses and schists occur in layers of sharply contrasting mineral composition. These layers range in thickness from a fraction of an inch to several feet; individual layers maintain almost constant thickness for distances of some tens of feet. The layers differ from one another in kinds or proportions of minerals and in grain size; most have distinct contacts though some are gradational. The inequidimensional mineral and rock constituents of these rocks are aligned parallel to one another and to the compositional layers. These rocks, then, have bedding foliation rather than axial plane foliation. In a few places where small folds have been observed in gneiss and schist, both compositional layers and foliation have been bent alike and remain parallel to one another along the fold axes. The structual symbols of Figure 1 for high-rank rocks thus give the orientation of both foliation and of bedding.

Strain-slip cleavage and fracture cleavage are superimposed on the foliation or flow cleavage in some places. The significance and age of these results of later deformations are not considered in this paper.

Major Folds

The dominant structural feature is the great southward plunging anticlinorium with granitic core whose crest extends north-northeastward through the center of the region. This uplift is referred to in this report as the Wake-Warren anticlinorium from its location in these counties. The rocks on both flanks dip steeply in most places and seem to have been closely, and in places isoclinally, folded, Some anticlinal and synclinal axes have been recognized in these flank areas but others are conjectural. Two generalized and tentative cross-sections are presented in Figure 1.

Wake-Warren anticlinorium. -- This great uplift has a core of granitic plutons (Rolesville granite, and others in Warren County), flanked with high-rank gneisses and schists that grade outward into low-rank metamorphic rocks. Both the lithologic and the structural elements in the region swing through a semicircle from the east side around the south end to the west flank, generally paralleling the borders of the granite. The trends of slates as far away as 30 miles from the pluton to the southeast and southwest, near Goldsboro and Erwin, still conform to this swing. Foliation and layering in the wall rocks are steeply inclined (usually 50 to 90 degrees) and in most places they dip away from the granite. The breadth of this uplift is at least 30 miles; it extends northeastward in North Carolina some 90 miles and continues beyond the state boundary into Virginia. Plunge of this fold southward is very steep, perhaps 70 degrees. Foliation within the Rolesville granite, where this has been determined, likewise seems to share the structural curve of the wall rocks. To the north, in the area near the state line (section A-A'), the crest of the anticlinorium is broad and appears to consist mainly of gently to moderately dipping gneisses and schists in a series of irregular folds. No detailed mapping has been done in this area. The northern end of this anticlinorium must lie in Virginia far beyond the limits of this report.

Spewmarrow syncline. -- The northwest corner of the region under discussion, in the Hamme tungsten district, lies on the west flank of the Wake-Warren anticlinorium (see section A-A'). The prevailing dip across this district is steeply westward into the southward plunging Spewmarrow syncline (Parker, 1963, p. G 60-G 61, and plate 2). Here metavolcanic rocks swing through a half-circle concave southward around this axis, on which is also located a hornblende gabbro stock. The Spewmarrow syncline is about 12 miles east of the Virgilina synclinorium (Laney, 1917, p. 42-46); apparently an unmapped anticline lies between the two (Parker, 1963, p. G 60). The Spewmarrow syncline extends southward into unmapped territory beyond the area under discussion.

Angier syncline. -- Southwest of the Wake-Warren anticlinorium the low-rank rocks extend northward in a narrow tapering projection. In the vicinity of Angier strikes change abruptly from northwest to south-southwest, evidently marking the axis of a tight south-plunging syncline. Most of this structure is buried under Coastal Plain sediments. Northward it seems to merge into the westward dipping homocline of various rocks to the west of Raleigh.

Raleigh anticline. -- A belt of quartz-microcline-biotite gneiss, in part kyanitic, passes north-northeastward through the western part of Raleigh. This rock has strong lineation consisting of linear streaks of biotite and of prisms of quartz. At places tight small scale flowage (similar) folds may be seen. Foliation and layering locally bend abruptly from nearly horizontal to vertical dips. Mineral lineation and minor fold axes are horizontal or plunge less than ten degrees throughout this belt; they trend parallel to local and regional foliation. To the east of this belt most dips are steeply eastward or vertical, while to the west they are moderate and westward (Figure 1 and section B-B'). This strongly lineated rock is presently interpreted by the writer as marking an anticlinal axis along which very tight folding has broken complex minor folds into small elongate segments (fold mullions) that lie horizontally, thus obliterating the layering in much of the rock.

Mamers dome. -- In the southwest corner of the mapped area (Figure 1), between Lillington and Sanford, is a broad area of low to moderate dips in high-rank rocks. Over a rather wide area north of the town of Mamers the layering and foliation are essentially horizontal. This dome lies west of the Angier syncline. Its western side is truncated by the Jonesboro fault that bounds the graben of Triassic rocks, and on the south it is covered by the wide westward transgression of Coastal Plain sediments.

East flank structures. -- The east side of the Wake-Warren anticlinorium is little known. No detailed areal mapping of basement rocks seems to have been done here. Exposures are few and widely scattered, owing to low relief and extensive outliers of Coastal Plain sediments on the interfluves (not shown in Figure 1). It is doubtful that an adequate picture of the structure here is obtainable.

Throughout most of this area structural attitudes are nearly vertical with northeast strikes. Steep westward dips are about three times as numerous as easterly dips. Low-rank "slate-belt" type rocks underlie most of the area, except for the vicinity of Littleton near the state line.

A large area near Essex has horizontal and gently dipping foliation in both low-rank and high-rank rocks. This may be a structural dome, abruptly downfolded on the east side (section A-A'). In a few places, for example at a point 12 miles northwest of Goldsboro, groups of readings with opposite dips suggest fold axes, but these have not been confirmed.

SUMMARY

The character, distribution, and structure of the metamorphic and igneous rocks in the northeasternmost part of the North Carolina Piedmont present a picture of a vast thickness of sedimentary and volcanic material, deposited under eugeosynclinal conditions during the early Paleozoic (and perhaps late Precambrian) era, that was closely compressed in an east-west direction, metamorphosed to varying grades up to almandine-amphibolite facies, and injected by mafic and felsic plutons during late Paleozoic time. These rocks now form a huge anticlinorium with core of granitic plutons that plunges steeply southward and that has subsidiary but large folds on both flanks. The margins of similar structures are suggested by fragmentary exposures to the east and west where they are covered by younger sediment.

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SPILITIC AMYGDALOIDAL BASALT FLOW ROCKS AND ASSOCIATED PILLOW STRUCTURE IN ORANGE COUNTY, NORTH CAROLINA

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ABSTRACT

Pillowed spilitic amygdaloidal basalt flow rocks have been recognized at five locations in the metavolcanic pyroclastic rocks and volcaniclastic epiclastic rocks of Orange County, North Carolina. These pillowed spilitic basalt lavas are the first such flow rocks to be recognized, identified and described in the metavolcanic rocks of the Carolina Slate Belt in North Carolina. The presence of pillow structure and the spilitic composition of the basalt flow rocks strongly suggests that the metavolcanic rocks of the area are of eugeosynclinal deposition. The basalt flow rocks follow the regional northeast trend of the metavolcanic rocks in the area and dip vertically or steeply northwest. In places, the spilitic amygdaloidal basalt flow rocks are interbedded and overlain by basaltic tuffs that exhibit excellent graded bedding. This data further indicates that, in places, the basalt flow rocks and interbedded tuffs are of subaqueous deposition.

LOCATION AND DESCRIPTION OF AREA

Orange County is located in the northern Piedmont of North Carolina within the Piedmont Plateau physiographic province. It falls within the area commonly known as the Carolina Slate Belt and contains three major rock groups which from oldest to youngest are: (1) Metavolcanic-metasedimentary rocks of Lower Paleozoic age (?); (2) Igneous intrusive plutonic rocks and plutonic complexes that range in composition from ultramafic through gabbro to granite and are of Middle to Late Paleozoic age; and (3) Undifferentiated sedimentary rocks of Upper Triassic age, Newark group, which occupy a portion of the downfaulted Durham basin in the extreme southeastern corner of the county.

The subaerially and subaqueously deposited low-rank metavolcanic-metasedimentary rocks of basaltic through rhyolitic composition have been tightly folded and faulted into a series of northeast trending asymmetrical folds some of which are overturned.

Pillow structures present at several locations along strike in the amygdaloidal basalt flow rocks indicate at least part of the flows were deposited in an aqueous medium. The pillows grade both laterally and vertically into homogeneous basalt flow rocks and in places are overlain by basaltic tuffs exhibiting graded bedding.

DISTRIBUTION AND DESCRIPTION OF SPILITIC BASALT FLOW ROCKS

Amygdaloidal basalt lava flows of the spilitic variety are located in central Orange County and follow the regional northeast trend of the metavolcanic rocks. The flows strike between N 25° and 35°E, dip steeply northwest to vertical and range from 0. 5 mile to over 6 miles in length and from 0. 1 mile to one mile in width.

Three flows are located just east and south of the town of Efland and four flows crop out just south and east of Hillsborough, North Carolina. An eighth flow occurs west of New Hope Church, 0. 5 mile west of the intersection of Highway N. C. 86 and Secondary Road 1732 and an ninth flow is located approximately one mile east of the intersection of Highway N. C. 86 and Secondary Road 1718 and crops out along the east bank of New Hope Creek.

In outcrop, the metabasalts are massive, have a hackly fracture and exhibit no apparent layering or cleavage. Weathering of the basalts produces a medium grayish-green surface which tends to emphasize flow lines and the knobby weather resistant quartz-epidote amygdules. The white and green-colored amygdules are spherical to oval in shape and the area around them is distinctly greener than the bulk of the matrix, as a result of a concentration of epidote in the vicinity of the amygdules. Sizes of the amygdules are varied but the majority range in size from a fraction of an inch to one inch in diameter. These amygdules were apparently formed by secondary mineral deposition in vesicles in the basalt flows.

DESCRIPTION AND LOCATION OF PILLOWS

Pillow structures of varying sizes and shapes have been observed at five locations in the spilitic basalt flow rocks of Orange County, North Carolina. Most of the pillowed outcrops show deformation of the pillows and at these locations, only a few of the pillows exhibit V-shaped bottoms. The shapes of the majority of the pillows in the outcrops exhibiting deformation are loaflike or irregularly subelliptical to amoeboid. With few exceptions, the pillows are longer than they were high and vary in length from 1 to 3 feet, with 2 foot lengths the most common. The measured height of the individual pillows range from 12 to 18 inches. Most of the pillows observed contained flow structure and quartz-epidote amygdules which, because of weathering, contribute a

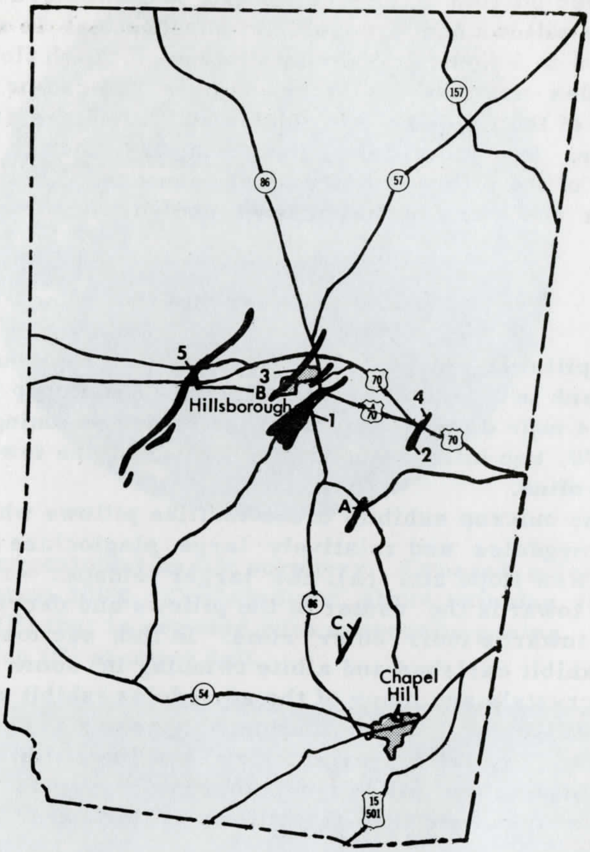

Figure 1. Location of basalt flow rocks in Orange County, N. C. 1-5 specimen locations, A-C pillow locations.

knobby uneven texture to the pillowed surface. Both amygdules and flow lines are present in the matrix surrounding the rims of the pillows and the flow lines can be easily traced as they wrap around the periphery of the pillows.

New Hope Site (A)

A pillowed amygdaloidal basalt flow (Figure 1, location A), is located approximately 0.5 mile west of the intersection of Highway N. C. 86 and Secondary Road 1732. The outcrop is located in a wooded area 500 feet south of Secondary Road 1732. The flow crops out for a distance of approximately 300 feet, is approximately 50 feet wide and in places the outcrop stands 10 feet above the surrounding ground surface.

The pillowed portion is located on the southwestern end of the outcrop area. The pillows are irregularly subelliptical in shape and range in size from 1 to 3 feet in maximum dimension. Both flow lines and trains of amygdules are present in the outcrop and can be traced around the periphery of the pillows. Amygdules and flow lines are also present in the pillows. In some pillows, the grain size tends to increase from the periphery of the pillows towards their centers. This would seem to indicate that the rims of the pillows cooled more rapidly than their interiors.

Eno River Site (B)

A pillowed amygdaloidal basalt flow crops out along the southeastern bank in a bend of the Eno River. The outcrop is located approximately 0.4 mile downstream from the bridge spanning the river on U. S. Highway 70, two miles west of the center of the town of Hillsborough, North Carolina.

The outcrop exhibits crude loaflike pillows which contain quartz-epidote amygdules and relatively large plagioclase feldspar crystals. As in the New Hope site (A), the larger feldspar crystals appear concentrated towards the center of the pillows and decrease in size and abundance towards their outer rims. In thin section, the matrix of the basalts exhibit carlsbad and albite twinning in some of the plagioclase feldspar crystals and many of the amygdules exhibit well-shaped actinolite fans (Figure 2a, 2b). Jointing is present in the pillowed outcrop and tends to parallel the exterior rims of the pillows. However, jointing also bisects the pillows in numerous places and in a few locations three dimensional views of the pillows are exposed.

New Hope Creek Sites (C)

A pillowed amygdaloidal basalt flow rock crops out in three distinct locations along the east bank of New Hope Creek. Three pillowed outcrops exhibiting flow structure and abundant amygdules are located downstream from the bridge spanning New Hope Creek on Secondary Road 1718, one mile east of the intersection of Highway N. C. 86 and Secondary Road 1718. The basalt flow strikes N 25 E, dips vertically and is easily traced overland as it parallels the regional northeast trend of the metavolcanic rocks in the area.

The first pillowed outcrop is located approximately 400 feet downstream from the bridge on the east bank of New Hope Creek. The outcrop exhibits deformed subelliptical to loaflike pillows that measure approximately 20 to 22 inches in length and 12 to 14 inches in width. Because of the absence of V-shaped bottoms on the pillows and their deformed shapes, the top and bottom orientation of the pillows in the outcrop could not be determined.

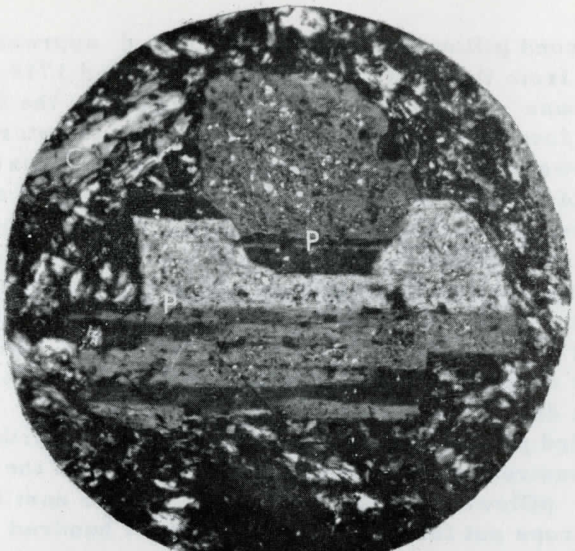

Figure 2a. Amygdaloidal basalt porphyry. Crossed polarizing prism; magnification 100X. Carlsbad and albite twinning in plagioclase feldspar (P) that is crowded with saussurite grains. Note ragged chlorite fan (C) at upper left.

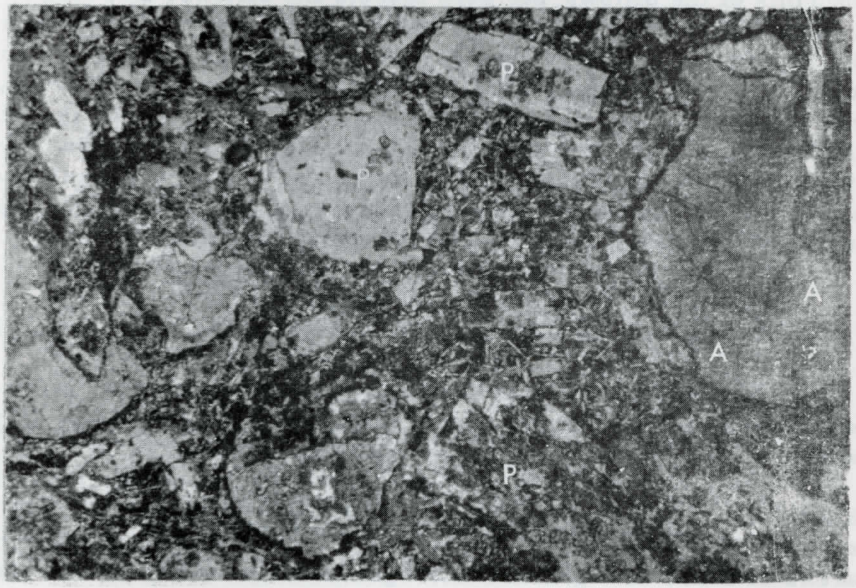

Figure 2b. Amygdaloidal basalt flow. Plain light; magnification 24X. Vesicle in upper right has been filled with actinolite fans (A) forming an amygdule. Note twinned plagioclase laths (P) that are riddled by dust-size epidote and chlorite grains.

A second pillowed outcrop is located approximately 800 feet downstream from the bridge on Secondary Road 1718. The outcrop is on the east bank of the creek and is situated in the first bend of New Hope Creek downstream from the bridge. This outcrop exhibits well-formed pillows, many of which have V-shaped bottoms (Figure 3a). The orientation of the tops and bottoms of the pillows indicates that the tops of the pillows face southeast. The pillows measure approximately 14 to 18 inches in length and 8 to 12 inches in width. The majority of the pillows observed contain amygdules. Flow lines and trains of amygdules are visible in the matrix and can be traced as they wrap around the periphery of many of the pillows in the outcrop. Numerous pillows at this location exhibit a coarse-crystalline center which grades laterally outward to a dense, fine-grained rim.

A third pillowed outcrop is located along strike approximately 800 feet downstream from the outcrop described in the preceeding paragraph. The pillowed basalt is located on the east bank of New Hope Creek and crops out for a distance of several hundred feet. The pillows observed in the northern end of the outcrop appear sheared and are deformed. V-shaped bottoms are not clearly defined and the orientation of the tops of the pillows at this particular point is uncertain. The pillows appear elongated and are subelliptical to loaflike in shape (Figure 3b). Most of the pillows are wider than they are high, but the proportions of others are reversed. Jointing in the outcrop not only parallels the rims of the pillows but also bisects the pillows, allowing in places a three dimensional view of the pillow structure. The southern end of the outcrop exhibits pillows that show less deformation and appear well-formed. V-shaped bottoms are present in numerous pillows and indicate that the orientation of the tops of the pillows face southeast. Flow lines and amygdules are present in the outcrop and, as in other locations, can be easily traced around the periphery of the pillows. The shape and size of the pillows vary in this location from subelliptical to loaflike to well-formed pillows with V-shaped bottoms.

CHEMICAL ANALYSES OF SPILITIC BASALT FLOW ROCKS

Table 1 contains the chemical analyses of five selected hand-specimens of basalt lavas from Orange County, North Carolina. The specimens showed little or no apparent weathering.

Specimens 2 and 3 were selected from basalt outcrops which exhibit an abundance of amygdules of varying sizes surrounded by irregular flow lines, whereas specimens 1, 4 and 5 were collected from areas of dense fine-grained homogeneous basalt lava which were void of amygdaloidal structure.

The chemical analyses in Table 1 show that the five basalt lavas contain a relatively high percentage of sodium oxide and a low percentage of potassium oxide. The average sodium oxide content of the five

Figure 3a. Well-formed V-shaped pillow structure occurring in the second outcrop of the New Hope Creek site located on the east bank of New Hope Creek, 800 feet downstream from the bridge on Secondary Road 1718. This relatively small pillow has a width of approximately 9 inches and a height of 6 inches. Flow lines and amygdules wrap about the periphery of the pillow in the surrounding basalt matrix. The base of the V-shaped pillow is coincident with the existing joint system. The orientation of the top of this pillow is to the southeast.

Figure 3b. Cluster of ameoboid and subelliptical pillows located in the third outcrop of the New Hope Creek site situated on the east bank of New Hope Creek, approximately 1,425 feet downstream from the bridge on Secondary Road 1718. The outcrop measures 3 feet high by 2 feet wide. The pillow in the center of the outcrop is approximately 18 inches in length and 8 inches in width.

Table 1. Chemical analyses of five spilitic basalt flow rocks.

	1	2	3	4	5
SiO_2	53.6	52.6	50.5	50.7	50.0
Al_2O_3	16.4	17.1	19.4	16.7	18.0
Fe_2O_3	6.0	2.5	4.3	3.1	7.3
FeO	4.0	6.2	5.7	7.6	2.3
MgO	3.5	5.1	4.7	5.6	5.1
CaO	9.2	7.8	6.4	5.8	9.7
Na_2O	3.1	3.8	3.9	3.8	3.0
K_2O	.77	.64	.27	.88	.70
H_2O-	.06	.07	.12	.07	.11
H_2O+	1.5	2.5	3.4	3.9	2.3
TiO_2	.97	1.0	1.0	1.2	.90
P_2O_5	.16	.23	.13	.24	.22
MnO	.23	.25	.15	.27	.26
CO_2	.05	.10	.05	.05	.05
Sum	99	100	100	100	100

analyses is 3.5 percent and average potassium oxide content 0.65 percent.

Because of the high sodium and very low potassium oxide content, the basalt flow rocks of Orange County are classified as spilitic. Turner and Verhoogen (1960) cite the chemical average of 19 spilites collected from various locations. These chemical analyses show an average sodium oxide content of 4.93 percent and an average potassium oxide content of 0.75 percent. Butler (1964) states that Laney's porphyritic greenstone of the Virgilina area are rather sodic, "and could be members of the spilitic-keratophyre group."

A graphic plot of silica against the ratio of potassium oxide to total alkalies (Figure 4) shows that the basalts fall within the chemical norm for the plotted average of spilites as defined by Nockolds (1954).

SUMMARY

The pyroclastic and epiclastic metavolcanic rocks of Paleozoic age in Orange County, North Carolina, also includes pillowed spilitic amygdaloidal basalt flow rocks which strongly suggest eugeosynclinal deposition. Pillow structure observed in five locations in the basalt lavas indicates that at least a portion of the flow rocks are of subaqueous accumulation. The basalt flow rocks are classified as being of the spilitic variety on the basis of the following data:

(1) A very low potassium oxide content which averages 0.65 percent and a relatively high sodium oxide content of 3.5

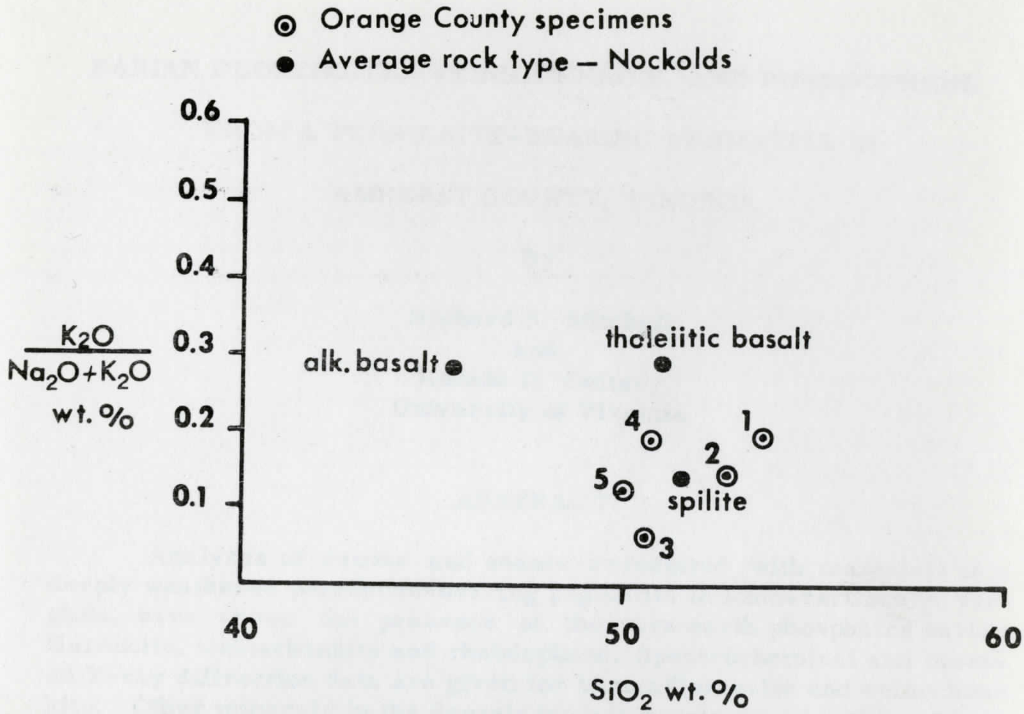

Figure 4. Plot of the ratio of potassium oxide to total alkalies against silica.

percent for the chemical analyses of the five basalt specimens.

(2) The presence of pillow structure in the basalt flow rocks indicates subaqueous deposition.

(3) In places, the basalt flow rocks are interlayered and overlain by basaltic tuffs which exhibit a pronounced graded bedding which is also indicative of subaqueous deposition.

(4) The basalt flow rocks exhibit flow structure and abundant amygdules which are indicators of a true extrusive rock.

(5) The complete chemical composition of the flows place them as true basalts and when their silica content is plotted against their ratio of potassium oxide to total alkalies, the basalts plot within the chemical norm for the plotted average of spilites as defined by Nockolds (1954).

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BARIAN FLORENCITE, WEINSCHENKITE, AND RHABDOPHANE FROM A PERRIERITE-BEARING PEGMATITE IN AMHERST COUNTY, VIRGINIA

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ABSTRACT

Analyses of crusts and seams associated with materials in a deeply weathered perrierite-bearing pegmatite in Amherst County, Virginia, have shown the presence of the rare-earth phosphates barian florencite, weinschenkite and rhabdophane. Spectrochemical and indexed X-ray diffraction data are given for barian florencite and weinschenkite. Other minerals in the deposit include perrierite, apatite, zircon, magnetite, ilmenite, quartz, microcline, biotite, anatase (after perrierite), lithiophorite and cerianite (?).

INTRODUCTION

X-ray diffraction studies of specimens from a deeply weathered perrierite-bearing pegmatite in Amherst County, Virginia, have shown several relatively uncommon minerals. The purpose of this paper is to report the minerals of the deposit, with emphasis on the secondary rare-earth phosphates which are quite abundant. The pegmatite is on the Marion Burley farm about 5 miles northwest of Amherst. The property is less than a mile south of U. S. Highway 60, on State Road 715. Old shallow pits in the weathered pegmatite are near the place where the meadow joins the woods on the high hill across the road and southeast of the Burley home.

The deposit was described by Pegau (1932) shortly after it was prospected. More recently it has been shown that allanite and chevkinite reported there by Pegau (1932) are actually perrierite (Mitchell, 1966). Geitgey and Mitchell (1966) and Geitgey (1967) have given preliminary reports on the mineralogy of the deposit.

Acknowledgments

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COMMENTS ON THE PEGMATITE

Although the pegmatite is deeply weathered, some of the primary minerals are still present. Large masses of black perrierite have been found (Mitchell, 1966). Pegau (1932), who mistook the mineral for allanite and chevkinite, recorded masses weighing 500 pounds. Weathered white chalky apatite, in anhedral pieces up to two inches across, is common. Analyses show the Ce rare-earth content to be rather high for the mineral, but this may be due to in part admixed florencite which is associated with it. Apatite probably is the source material for the phosphate common in the secondary minerals. Relatively small masses of white to blue-gray to black fractured quartz are abundant. Quartz crystals were not observed. Microcline, usually quite kaolinized, is the only feldspar identified with certainty, although one would expect additional feldspars in the deposit. Analyses of two microcline specimens showed BaO contents of 0. 8 percent and 0. 6 percent respectively. These values are higher than for any other primary minerals analyzed, and indicate microcline may be the source of barium in the barian florencite. Masses of magnetite and ilmenite are common in the deposit. Both minerals show well-developed parting planes. Schistose, medium-grained biotite is often associated with specimens of these iron and titanium oxides. Reddish-gray subhedral zircon masses, up to 2. 5 inches across, occur in the deposit. The mineral fluoresces orange-yellow under long- and short-wave ultraviolet radiation. Trace amounts of the yttrium rare earths were noted in zircon analyses.

Since the materials studied were not in place, and the pits are filled and deeply weathered, no evidence for the spatial relationships of the various minerals could be seen. The pegmatite apparently is expressed at the surface as a series of irregular bodies, none of which extends more than several tens of feet in any direction. Pegau (1932) noticed the pits have an alignment of N 30°E. According to the owner of the property one pit originally was at least 70 feet deep. One of the writers (RPG) unsuccessfully attempted to delineate the pegmatite body by using a radiation survey. The country rock is an altered quartz diorite (Pedlar Formation). The associated hypersthene granodiorite mentioned by Pegau (1932) was not observed. A float specimen of pyroxene-nelsonite (composed of uralite, ilmenite and apatite) was found, but the nelsonite dike reported by Pegau (1932) was not relocated. Apparently other similar pegmatites are in the area. Mitchell (1966) reported float pieces of perrierite (over 320 pounds) at Wares Gap in the same county, about 3. 25 miles southwest of the Burley farm occurrence.

SECONDARY RARE EARTH PHOSPHATES

A striking feature of the deposit is its very weathered condition. Although the pegmatite was probably deeply weathered before it was originally prospected, apparently considerable weathering has occurred in the 36 years since that time. The predominant material in the pits is iron-stained soil containing fragments of stained quartz, kaolinized feldspar and pieces of other altered minerals. White to reddish earthy and porcelaneous materials fill fractures or occur as crusts on these fragments. Studies of these crusts and narrow seams have resulted in the identification of the phosphate minerals discussed below. Although these secondary minerals are probably products of weathering, especially of perrierite and apatite, this origin is not certain.

Barian Florencite

The most abundant rare earth phosphate in the deposit is florencite which contains up to 4 percent BaO. The mineral occurs as dull earthy crusts up to 2 mm thick, especially on quartz. Fracture fillings and small botryoidal masses, often with hollow globules, are less common. Colors include various shades of red, orange, yellow, cream, brown, green and white. Staining by iron and manganese oxides apparently effect the coloration. Although most of the florencite is associated with quartz fragments, it was also found on ilmenite, magnetite, zircon and altered perrierite.

Semiquantitative spectrographic analyses were made of four different specimens. A typical one of these is presented in Table 1. In the analysis the ratio of cerium earths to yttrium earths is greater than 15:1. Aluminum and phosphorous are essential to the mineral. The high silicon is probably from admixed quartz or perhaps clay minerals, although some substitution of P by Si is theoretically possible. The relatively high percentage of BaO (over 4 percent in some analyses) is significant. This would indicate the mineral is in the series florencite-gorceixite. A strontian variety of florencite has recently been reported by McKie (1962).

X-ray data given in Table 2 were calculated from averaged values from five good films made in 11.46 cm diameter cameras with filtered copper radiation. Initially the interplanar spacings were indexed using data from McKie (1962). Unit cell dimensions, from which the final calculated values in Table 2 were obtained, are a = 7.01 Å and c = 16.23 Å. All possible calculated values through 1.38 Å are included in the table except for those missing for space groups with the diffraction symbol $\bar{3}$mR--.

Weinschenkite

Weinschenkite in the Burley farm pegmatite occurs principally as botryoidal crusts. Broken pieces show a radial development of very small fibers. The crusts are rarely thicker than 0.25 mm. Radiating needles as delicate clusters less than 0.5 mm in diameter were also noticed. The mineral is either opaque white to colorless.

Table 1. Semiquantitative spectrographic data on barian florencite, Amherst County, Virginia. Elements reported as oxides. Analyst: F. W. Barley, American Spectrographic Laboratories, San Francisco.

Element	Percent	Element	Percent
Be	0.015	Ba	2.
Mg	0.12	Pb	0.03
Al	35.	Th	0.2(?)
Si	17.5	Sc	0.01
P	15.	La	3.
Ca	0.2	Ce	4.
Ti	0.6	Pr	1.
V	0.02	Nd	3.
Cr	0.008	Sm	0.2
Mn	0.03	Eu	0.02
Fe	6.5	Y	0.25
Cu	0.02	Gd	0.3
Ga	0.003	Dy	0.1
Sr	0.7	Er	0.03
Zr	0.02	Yb	0.03

Weinschenkite is usually attached to pieces of ilmenite and magnetite although minor crusts occur on quartz, perrierite and zircon.

Two samples were subjected to semiquantitative spectrographic analyses. The purer of these is reported in Table 3. Silicon, aluminum, and iron are probably from admixed impurities. The yttrium rare earths are slightly in excess (11 percent) over the cerium rare earths (7 percent). This is in agreement with most published data for the mineral. An analysis of a second less pure sample showed a predominance of cerium rare earths, but relatively high percentages of aluminum in the sample indicate that traces of florencite or some other mineral may have interfered with this ratio.

X-ray powder data are given for weinschenkite in Table 4. Since the interplanar spacings for the Burley farm material agree so closely with those of Claringbull and Hey (1953) their unit cell dimensions were adopted in calculating values reported in Table 4. The values used are a = 5.61 Å, b = 15.14 Å, c = 6.19 Å, and, β = 115.3°. Characteristic extinction reflections of space group A/2a (Claringbull and Hey, 1953) were considered in the calculations. Calculated values less than 1.91 Å are not reported.

Rhabdophane

Dark reddish-orange rhabdophane crusts occur on quartz and

Table 2. X-ray powder data for barian florencite, Amherst County, Virginia. Filtered copper radiation. Cameras of 11.46 cm diameter.

hk·l	d(calc.)Å	d(meas.)Å	I(obs.)
10·1	5.69	5.68	vs
00·3	5.41		
01·2	4.87		
11·0	3.50	3.50	s
10·4	3.39	3.41	vw
11·3	2.95	2.95	vvs
01·5	2.88		
20·2	2.85	2.85	w
00·6	2.71	2.72	w
02·4	2.44	2.44	w
21·1	2.27	2.26	vw
20·5	2.22	2.22	m
12·2	2.21	2.19	ms
11·6	2.15	2.15	vw
10·7	2.13		
30·0	2.02		
21·4	2.00	2.00	w
01·8	1.94		
30·3	1.90	1.90	ms
12·5	1.88		
02·7	1.85		
00·9	1.80		
22·0	1.75	1.75	ms
20·8	1.69	1.70	vw
13·1	1.68		
22·3	1.67	1.67	vw
31·2	1.65		
21·7	1.64	1.64	vw
30·6	1.62	1.62	vw
11·9	1.61		
13·4	1.56		
10·10, 12·8	1.53		
40·1	1.51		
04·2	1.49		
22·6	1.47	1.47	vw
31·5	1.46 }		
02·10, 01·11	1.44	1.45	w
40·4	1.42		
32·1	1.39		
04·5	1.38	1.38	vvw
		1.32	vvw
		1.29	mw
		1.20	w
		1.17	vw

Table 3. Semiquantitative spectrographic data on weinschenkite, Amherst County, Virginia. Elements reported as oxides. Analyst: F. W. Barley, American Spectrographic Laboratories, San Francisco.

Element	Percent	Element	Percent
Mg	0.02	Sc	0.004
Al	1.25	La	1.25
Si	7.	Ce	1.
P	30.	Pr	0.6
Ca	0.2	Nd	2.5
Ti	0.6	Sm	2.5
V	0.02	Eu	0.04
Cr	0.008	Y	5.
Mn	0.015	Gd	1.
Fe	1.25	Tb	0.2
Cu	0.004	Dy	1.5
Sr	0.05	Ho	0.4
Zr	0.04	Er	0.8
Nb	0.05(?)	Tm	0.2
Ba	0.2	Yb	1.75
Pb	0.001	Lu	0.15

zircon. Usually the crusts are distinctively pitted or more rarely botryoidal. The mineral is the least common of the secondary phosphates. Although a pure sample could not be obtained for study, semiquantitative spectrographic analyses helped verify the mineral as a cerium rare earth phosphate and eliminated the possibility of this material being one of the closely related minerals like brockite, ningyoite or grayite. The cerium rare earths predominate over the yttrium rare earths by a factor of ten. The fairly high silicon, aluminum and iron content was shown by X-ray analysis to be due to mainly quartz, clays and goethite. The X-ray data for the rhabdophane, with unit cell dimensions of a = 7.01 Å, and c = 6.38 Å, are in very close agreement with those from Salisbury, Connecticut (Muto et al., 1959). A thorium rich rhabdophane from Amelia County, Virginia, has a slightly larger unit cell (Mitchell, 1965).

OTHER SECONDARY MINERALS

X-ray data close to those of cerianite were observed on one florencite film. Attempts to isolate the mineral failed, and no other specimen yielded similar data. The unit cell calculated from these data has a = 5.40 ± 0.02 Å. Although X-ray data for uraninite also fall in this range the chemistry of the deposit supports cerianite better.

hkl	d(calc.) Å	Amherst County, Va. d(meas.) Å	I	Cornwall* d(meas.) Å	I
020	7.57	7.50	vs	7.50	vs
011	5.25	5.22	w	5.22	mw
$\bar{1}11$	4.71	4.68	m	4.70	m
120	4.21	4.18	vvs	4.21	vvs
040	3.79				
031	3.75	3.74	ms	3.74	m
$\bar{1}31$	3.54				
111	3.08				
140	3.03	3.01	s	3.02	vs
$\bar{1}22$	2.84	2.83	ms	2.82	ms
002	2.80				
$\bar{2}11$	2.76				
131	2.67				
051	2.66				
022	2.62	2.61	m	2.62	m
$\bar{1}51$	2.58				
200	2.54				
060	2.52	2.51	m	2.51	mw
$\bar{2}02$	2.48				
$\bar{2}31$	2.45	2.45	w	2.46	mw
220	2.40	2.38	m	2.39	mw
$\bar{1}42$	2.38				
$\bar{2}22$	2.36				
160	2.26				
042	2.25				
151	2.18	2.16	ms	2.17	m
240	2.11				
$\bar{2}42$	2.07				
$\bar{2}51$	2.06				
$\bar{1}13$	2.04	2.04	mw	2.05	mw
122, 071	2.02				
211	1.99	2.00	vw	2.01	vvw
$\bar{1}71$	1.98	1.97	w	1.97	mw
$\bar{1}62$	1.95				
$\bar{2}13$	1.94	1.93	vw	1.94	vvw
$\bar{1}33$	1.91				
		1.86	mw	1.861	m
		1.83	w	1.825	mw
		1.78	ms	1.776	m
		1.76	mw	1.755	w
		-		1.692	vvw
		1.65	w		
		1.64	mw	1.643	mw
		1.60	mw	1.600	mw
		1.56	w	1.560	vw
		1.53	w	1.535	vw

* From Claringbull and Hey (1953).

Table 4. X-ray powder data for weinschenkite. Filtered copper radiation. Cameras of 11.46 cm diameter.

Anatase is a major component of weathered perrierite and also occurs associated with ilmenite masses. Anatase pseudomorphs after perrierite masses are quite numerous in the deposit (Geitgey and Mitchell, 1966). The masses, which measure up to several inches across, are dull, earthy and light brown, and are appreciably radioactive. Occasionally they contain unaltered black pitchy perrierite at their centers. The crusts and pseudomorphs have been shown by X-ray analyses to be composed primarily of anatase with traces of quartz, and at times other minor impurities such as iron oxide. Semiquantitative spectrographic analyses verify these compounds and also show numerous trace elements, including such things as aluminum, zirconium, thorium (the cause of the radioactivity), cerium, and neodymium. Perrierite altered to anatase has also been found in other Virginian localities (Mitchell, 1966).

Other secondary minerals at the locality include the clays, kaolinite and metahalloysite, goethite and lithiophorite. Mitchell (1967) has recently shown that lithiophorite is a very common secondary manganese mineral in Virginia.

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MINERALOGY OF CHLORITE-TALC SCHIST FROM WASHINGTON, D. C.

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ABSTRACT

A Frantz Isodynamic Magnetic Separator was used to study the mineralogical composition of soapstone from northwest Washington, D. C. Chlorite, talc, magnetite, rutile, sphene, zircon, quartz, muscovite and apatite are present. A norm calculation of the chemical analysis reveals a pyroxenite genesis.

INTRODUCTION

Several bodies of a chlorite-talc schist "soapstone" outcrop sporadically throughout the western sequence of the Wissahickon metasediments of Montgomery and Howard Counties, Maryland, as well as nearby District of Columbia. Hopson (1964) reports that the lenses are abundant in Montgomery County between Gaithersburg and Woodfield. Fellows (1950) notes at least two occurrences in the area of Rock Creek Park in Washington, D. C. Recent work by Tilton et al., (1959) on the problem of age determination for the regional metamorphism revealed significant findings. They report clear evidence of Precambrian metamorphism of 1100 million years ago. By this time the Baltimore Gneiss and the Hartley Augen-gneiss were crystallized. These authors also found evidence of a regional Cambrian-Ordovician intrusion of pegmatites and probably granites dated as 450 million years ago. Another event of 300 million years ago is indicated by age measurements on biotite. The authors note the possibility of these being high points of one long orogenic period of metamorphism.

The most prominent local soapstone outcrop in the Washington area is situated at 46th Street and River Road in northwest Washington, D. C. The rock is exposed in three places, trending east-west for about two hundred feet. Intruded veins of chlorite generally trend N 89° W with a 70° dip, filling tensional fractures. One vein of coarse talc was observed trending N 72° W.

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TECHNIQUE

In this study, unweathered samples were collected laterally across the outcrop on a grid system. The specimens of roughly consistant size were crushed, pulverized, seived to standard mesh sizes and thoroughly mixed. A split of the 35-60 mesh size was selected for study. This 345.50 gram sample was separated in bromoform into 23.59 grams of heavy and 310.51 grams of light minerals. A magnetic portion weighing 12.59 grams was then removed by a hand magnet from the heavy minerals. The remaining 10.91 grams of the heavies, as well as a 20.00 gram split of the light minerals was next prepared for separation on the Frantz Isodynamic Magnetic Separator. It was observed that a more effective separation was achieved if the samples were first bathed for one hour in an ultrasonic cleanser. Experimentation revealed that a 25° forward and side tilt on the Frantz Separator achieved the most satisfactory results. All mineral identifications were made with index of refraction liquids, supplemented by X-ray techniques on a Philips diffractometer using Cu-Kα radiation. Percentages of minerals present in the separations on the Frantz Isodynamic Magnetic Separator were determined by a grain-count. The percentages of inclusions, notably magnetite and rutile, was estimated visually.

FRANTZ SEPARATION

The high degree of magnetite inclusions in the 12.59 grams removed by hand magnet from the Bromoform heavy portion prevented further effective separation of these. The percentage of magnetite, forming inclusions of octahedra habit is about 10 percent. Inclusions of magnetite were more notable in the chlorite than the talc. Composition of this sample was 42 percent chlorite, 38 percent talc with trace amounts of sphene and limonite.

The heavy minerals separated in bromoform that were not affected by the hand magnet were further separated on the Frantz Isodynamic Magnetic Separator with the following results:

A.	0.2 amps	0.40 grams	53% talc, 37% chlorite, < 10% magnetite as inclusions, < 5% goethite, trace limonite.
B.	0.4 amps	0.87 grams	58% chlorite, 32% talc, < 5% goethite, 5% magnetite as inclusions, trace rutile.
C.	0.6 amps	4.75 grams	49% chlorite, 51% talc, trace amounts of magnetite, goethite and rutile.
D.	0.8 amps	4.15 grams	54% talc, 41% chlorite, < 5% rutile as inclusions, trace amounts of magnetite as inclusions and trace zircon.
E.	1.0 amps	4.90 grams	98% talc, 2% rutile as inclusions, trace amounts of muscovite and zircon.
F.	1.0^{+} amps	0.09 grams	63% apatite, 22% quartz, 11% zircon, 4% pyrite, < 1% rutile and sphene.

A 20.00 gram split of the 310.10 gram bromoform light was separated on the Frantz Isodynamic Magnetic Separator with the following results:

A.	0.1 amps	0.40 grams	44% chlorite, 52% talc, < 4% magnetite as inclusions.
B.	0.2 amps	0.35 grams	78% chlorite, 22% talc, < 1% magnetite as inclusions.
C.	0.6 amps	9.85 grams	81% chlorite, 19% talc, trace amounts of rutile, sphene and magnetite.
D.	0.7 amps	3.44 grams	74% talc, 26% chlorite, trace sphene.
E.	0.8 amps	4.90 grams	100% talc, trace sphene inclusions.
F.	0.8^{+} amps	0.95 grams	100% talc, trace sphene inclusions.

Optically the chlorite has properties associated with ripidolite with $n\alpha = 1.602$. Individual chlorite cleavage fragments contain upwards of fifty percent magnetite octahedra inclusions by volume. Brownish red acicular rutile observed in the chlorite is often present as geniculated twins. Rutile and magnetite inclusions were present to a lesser degree in the talc grains. Magnetite inclusions were also present in the muscovite and quartz. Sphene is associated with the talc. One particular amber-yellow grain had prominent parting parallel to (221) with (100) twin-plane parallel to the length of the section. The apatite present tends to be translucent white to colorless.

Goethite pseudomorphs after pyrite vary widely in size and habit. The largest observed specimen was 16 mm on edge. Elongation of the c-axis with small octahedra modification predominates. Simple cubes were rarely observed. In two specimens oscillatory growth produced stepped and slightly rounded faces. Replacement of the pyrite by goethite was usually complete, though several of the larger crystals retained a pyrite core.

CHEMICAL ANALYSIS

A chemical analysis (Table 1) was performed by P. Elmore, L. Artis, G. Chloe, H. Smith, J. Glenn, J. Kelsey and S. Botts of the U. S. Geological Survey on March 19, 1968. Methods used are those described in U. S. Geological Survey Bulletin 1144-A, supplemented by Atomic Absorption.

Table 1

Lab No. W170069

SiO_2	55.1		
Al_2O_3	4.2		
Fe_2O_3	1.1	Norm Calculation	
FeO	6.9		
MgO	26.6	apatite	.08
CaO	.08	ilmenite	.22
Na_2O	.08	orthoclase	.55
K_2O	.11	albite	.85
H_2O^-	.12	corundum	4.42
H_2O^+	5.0	magnetite	1.17
TiO_2	.15	enstatite	74.34
P_2O_5	.04	ferrosilite	9.74
MnO	.12	quartz	8.43
CO_2	.06		
		Sum	99.80%
Sum	100. %		

Hopson (1964) views that the regional soapstone was derived from an existing serpentinite body. A norm calculation of the chemical analysis (Table 1), however, reveals that it was probably derived from a pyroxenite body. The geologic relationships indicate the intrusion of the pyroxenite body into the Wissahickon metasediments. Subsequently, more intense metamorphism, accompanied by metasomatism altered the pyroxenite body into a chlorite-talc schist and the surrounding Wissahickon to a higher rank. The excess of silicon and aluminum seems to have been derived locally from the Wissahickon country rock.

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BRYOZOAN PALEOECOLOGY FROM THE TERTIARY OF ALABAMA

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ABSTRACT

In the last few decades several investigators have successfully related bryozoan colonial forms to ecologic conditions. This relationship was used in examination of bryozoa from an upper Eocene and Oligocene section from St. Stephen, Alabama. Samples were processed from the Yazoo Clay, Red Bluff Clay, "Forest Hill" Sand, Marianna Limestone, Byram Formation and Chickasawhay Limestone. Simultaneous with an increase in terrigenous material in successively younger samples, especially in the Glendon Limestone Member of the Byram Formation and Chickasawhay Limestone, there was a pronounced increase in those colonial forms thought to be better adapted to more agitated, neritic conditions.

INTRODUCTION

The purpose of this study is to make a paleoenvironmental reconstruction of conditions which prevailed during the deposition of upper Eocene and Oligocene marine sediments near St. Stephens in southwest Alabama. The method is based on the use of growth-form classifications of bryozoa which reflect adaptions to different environmental conditions. Groupings based on the shape of the bryozoan colony (zoarium) instead of on the shape of the individual bryozoan animal (zooecium) are source of the data. Fossils here called bryozoa are often referred to as ectoprocts (Phylum Ectoprocta) in zoological and paleontological literature. However, for ease of general understanding I am using "bryozoa" in a non-technical sense.

Stach, a pioneer in studies of bryozoan growth forms, stated that (1936) "A study of zoarial form in the cheilostomatous Bryozoa has shown that a definite relationship exists between the various zoarial types and their habitat." The particular feature of the habitat which influenced the zoarial type in Stach's work on the Cenozoic of New Zealand was thought to be the nature of the substrate. Similarly, Rucker (1967) in his study of Cenozoic bryozoa along the coast of Venezuela and British Guiana, concluded that "sedimental substrate is the principal factor influencing the distribution of Bryozoa along the shelf." However, Lagaaij and Gautier (1965) concluded that "the rate of deposition [of sediment] ranks paramount among the factors that control the distribution of the Bryozoa.", and that temperature and depth also played important roles. This they determined from examination of Recent specimens from the Rhone Delta. Finally, Clebnik (1968) studied Recent bryozoa collected from an area stretching from Nova Scotia to Long Island Sound. He concluded that "In some cases, the limiting environmental condition coincided with that advanced by previous investigators (especially, Lagaaij and Gautier). In some cases, some feature in addition to that advanced by the previous writers was noted as being a limiting factor." He was able to find some correlations between colonial type and depth and/or substrate, but no universal limiting factor. Rate of sedimentation was largely excluded as a major factor in Clebnik's study because sedimentation is negligible over most of his area.

The publications of several authors who have worked in the Tertiary of Alabama are of interest here. Cheetham (1963) found eight cheilostome bryozoan species associations in the upper Eocene (Jacksonian) of the eastern Gulf Coast and, using Recent equivalents of fossil specimens, postulated values for the environmental conditions: salinity, 32-37 o/oo; temperature 20-22° C; agitation, moderate; and depth, 30-80 meters. On the basis of the environmental implications of his bryozoan associations, Cheetham divided the Jacksonian of the eastern Gulf Coast region into four provinces, Ocala Bank, Suwannee Strait, carbonate shelf and terrigenous shelf. The samples for the present study came from within the latter province.

Gardner (1957) studied the Eocene and Oligocene sections exposed along Little Stave Creek, which is a few miles east of St. Stephens along the strike of the old shoreline. Using the molluscan fauna, she hypothesized that

> "The entire sequence of Eocene and Oligocene sediments was probably laid down on a shifting shelf beyond the intertidal zone. The shores were low and not rocky. None of the load brought down by the streams was very coarse... The average depth of the water may have been 40 fathoms (73 meters) or less. The range in the probable depths and temperatures in the Little Stave section is so slight that it cannot be easily evaluated...The temperature of the water during the Eocene was probably as high as it is in the northern Gulf of Mexico today or higher. The Oligocene faunas lived under subtropical conditions."

Gardner cited work by T. W. Vaughan concerning foraminifers found in the Oligocene of Little Stave Creek which suggested a temperature range of 26-31° C and a depth of 0-100 meters.

Stephenson (1928) traced the movements of the Gulf of Mexico shoreline from Cretaceous to Recent times. He wrote (1928, p. 288-290) "In the central and eastern parts of the Gulf Coast Plain the Jackson sediments were followed without conspicuous evidence of unconformity by the Oligocene marine sands, clays, limestones, and marls of the Vicksburg group... The deposition of the Oligocene Vicksburg group was followed by uplift or tilting, the retreat of the strandline seaward, and erosion in the formerly submerged area."

In conclusion, the writers above as well as Bandy (1949) and Echols and Schaeffer (1960) have indicated that late Eocene-Oligocene reflected subtropical to tropical conditions in clear, shallow carbonate seas along a continental shelf, followed by late Oligocene uplift and a seaward-shifting shoreline.

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Contribution Number 57 from the Marine Science Center, Lehigh University, Bethlehem, Pennsylvania.

MATERIALS AND METHODS

The samples used in this study were collected by Thomas J. M. Schopf in November of 1967 from the Lone Star Cement Company Quarry at St. Stephens, sec. 2, T. 6N., R. 1E., Washington County, Alabama (Figure 1). The eight grab samples consisted of semilithified to unlithified marl of approximately 1 1/2-2 liters volume. The material was wet seived into four size fractions, 4 mesh, 10 mesh, 65 mesh and 100 mesh. All samples lost roughly 1/3 - 1/2 their volume as clay which was not retained by the 100 mesh seive. In all cases the largest fraction was the 65 mesh fraction and this was the one used because it held the great majority of bryozoa. Bryozoa were picked under the binocular microscope and separated into similar growth-form types. The percent terrigenous content was estimated.

A rigorous application of the methods of growth from classification was not attempted. More than 75 percent of each sample was represented by 3 growth-forms and the conclusions are based on major variations in these.

RESULTS

Figures 2 and 3 show the results of this investigation. In Figure 2, erect bryozoa occupy greater than 90 percent of the whole through

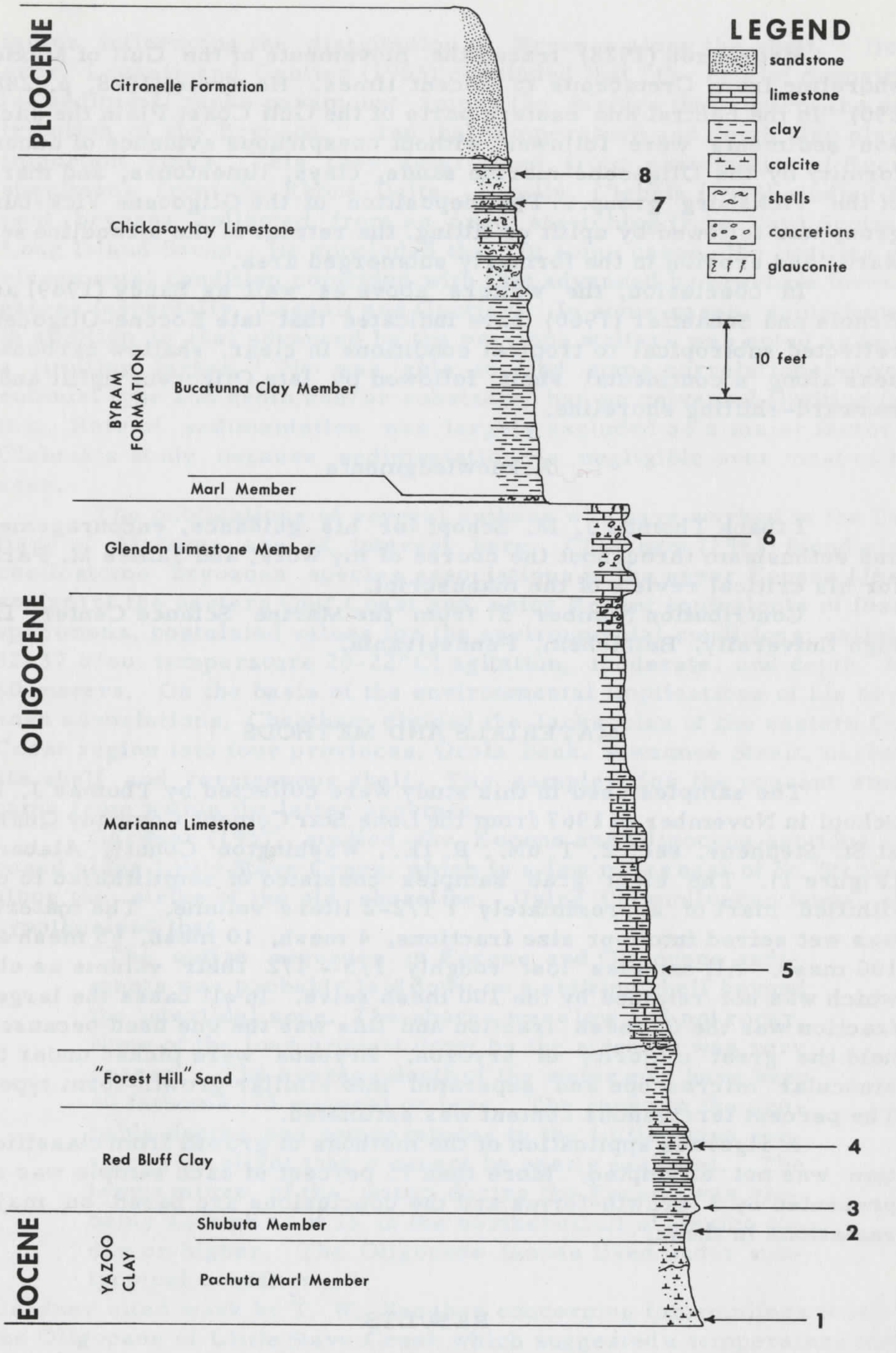

Figure 1. Geologic section at Lone Star Cement Company quarry at St. Stephens, Alabama. From Jones (1967). Numbers to the right indicate samples.

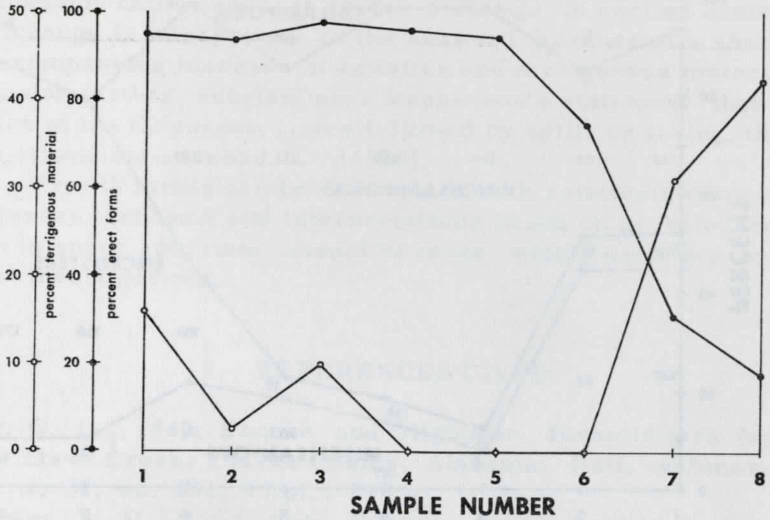

Figure 2. Percent terrigenous matter and percent erect forms for each sample.

the first five samples and then decline to 76, 30 and 13 percent, respectively, in the last three. Terrigenous content (as quartz grains and shale flakes in the carbonate sediment) climbs from 15 percent or less in the first six samples to 30 and 40 percent, respectively, in the last two samples. Figure 3 shows the percentage distribution of three colonial forms. Cellariiform denotes a type of erect branching colony which has flexible chitinous joints at branch junctions, allowing movement and bending in response to water currents. The percentage of this type seems to vary irregularly. Vinculariiform denotes a type of erect branching colony which lacks flexible joints and is therefore rigid. The percentage of this type is moderate in samples 1 and 2, greatest in samples 3, 4 and 5, decreases in sample 6, and drops to zero in samples 7 and 8.

The third major group is broadly referred to as encrusters. These include those bryozoans which attach themselves to objects such as molluscs, echinoderm plates, foraminifera, rock fragments, and algae. They mold their skeletal attachment surface to the shape of the substrate and do not protrude for great distances into the water as do the erect forms. The highest percentages are found in samples 6, 7 and 8.

DISCUSSION

Two important relationships are shown by the data. First, encrusters replace erect forms as the amount of terrigenous matter

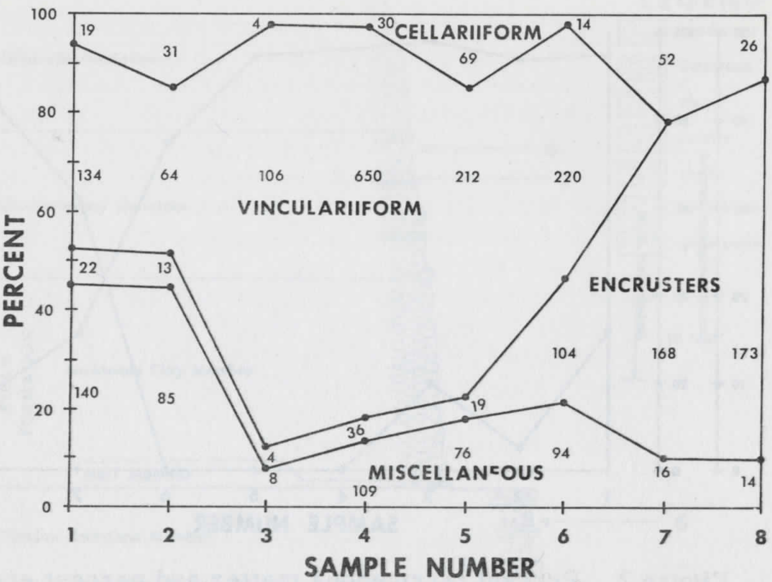

Figure 3. Distribution of three growth types. Cellariiform bryozoa are erect, jointed (flexible) forms. Vinculariiform bryozoa are erect, rigid forms. Numbers in each column indicate number of specimens.

increases. An increase in terrigenous matter may imply conditions nearer to shore and a higher energy environment. Erect forms would likely be broken in the turbulence and therefore not flourish. Alternatively, an increase in coarse material, including shell fragments, provides more substrates for encrusters. Opposing this effect may be the tendency for encrusters to be covered by the settling sediment, but this is probably a minor factor in an area changing from a low to moderate rate of sedimentation.

The second important relationship is that between the vinculariiform (rigid) to cellariiform (jointed) ratio and the quantity of terrigenous matter. The ratio of vinculariiform to cellariiform types is high in the first six samples, ranging from 2:1 to 28:1 and averaging 14:1, but drops to 1:84 in the last two samples. Understandable, rigid forms would be at a selective disadvantage as compared to jointed forms in more turbulent water. Rigid types may be more easily broken by sediment carried in the currents.

CONCLUSIONS

This study demonstrates that two simple growth-form based relationships can be used to detect a change in ancient environments. This change is interpreted as the seaward advance of a shoreline and the accompanying increase in agitation and terrigenous material. This conclusion further substantiates Stephenson's statement that "The deposition of the Oligocene. . . was followed by uplift or tilting, the retreat of the strandline seaward. . . " (1928).

Growth forms can be determined with relatively little knowledge of bryozoan taxonomy and interpretations based on growth-form distribution in space and time should be more widely used in paleoenvironmental investigations.

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A BORED ECTOPROCT FROM THE MIDDLE MISSISSIPPIAN OF TENNESSEE

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ABSTRACT

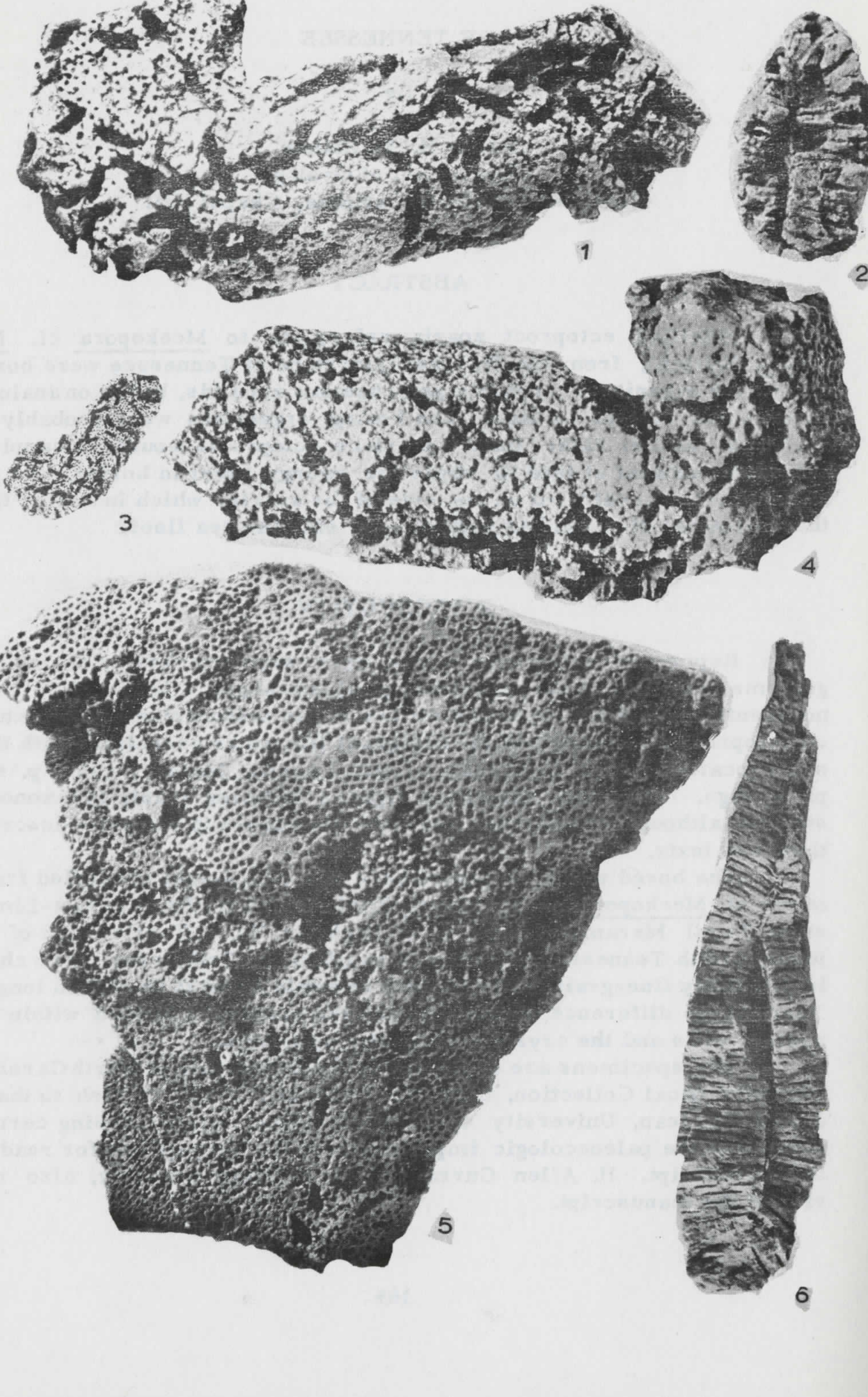
Silicified ectoproct zoaria referrable to Meekopora cf. M. clausa (Ulrich), from the Warsaw Limestone of Tennessee were bored by marine organisms, probably polychaetous annelids, based on analogy with Recent marine borings. The boring organisms were probably in search of shelter rather than food since ectoprocts would not supply a sufficient amount of food to repay the energy spent in boring, and the borings are concentrated on one side of the zoaria, which indicates that the zoaria had died and had toppled over onto the sea floor.

INTRODUCTION

Reports of ectoprocts which have been attacked by boring organisms are rare in the paleontological literature. Duncan (1957) did not mention bored zoaria in her review of the paleoecological literature on ectoprocts. A search of the ectoproct literature associated with this study located a single reference to bored zoaria (Hecker, 1965, p. 40, pl. 4, figs. 7-11), and numerous figures of bored zoaria in taxonomic studies, although the borings were not mentioned in the plate descriptions and texts.

The bored zoaria reported here are completely chertified fragments of Meekopora cf. M. clausa (Ulrich), from the Warsaw Limestone (basal Meramecian) on U. S. Highway 70, 2.7 miles east of the junction with Tennessee Highway 48 in Dickson, Tennessee. The chert is primarily fine-grained quartz with crystals about 0.06 mm in length. There is no difference in size between the crystals confined within the zoarial walls and the crystals lining the boreholes.

The specimens are deposited in the University of North Carolina Paleontological Collection, numbers 3913 and 3914. I wish to thank Joseph St. Jean, University of North Carolina, for discussing certain aspects of the paleoecologic implications of the borings and for reading the manuscript. H. Allen Curran, U. S. Military Academy, also reviewed the manuscript.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DESCRIPTION

The borings are small, with a smooth, circular cross-section (Plate 1, Figure 2). The borings average 0.6 mm in diameter with a standard deviation of 0.1 mm (Figure 1). The borings are distinct from the zooecia, which have maximum diameters of about 0.25 mm. There is no apparent clumping or patterned distribution of the borings other than a poorly developed alignment and coalescence of borings along a line close to and paralleling an edge of one of the zoarial branches. The borings are concentrated on one side of the bifoliate zoaria. The bore-holes on the more heavily bored side of specimen UNC 3913 are parallel and slightly oblique to the zoarial surface; on the less bored side the holes toward the center of the branch tend to be at a much higher angle to the surface. In places several of the borings coalesce to form irregular chambers up to 5.5 mm long, 2.5 mm wide, and 2.0 mm deep. The outer edges of the chambers intersect the zoarial surface. Most of the tubes appear to anastomose, but this anastomosing appearance may be a function of the borehole density.

DISCUSSION

The ectoproct colonies are tentatively identified with <u>Meekopora clausa</u> (Ulrich, 1884, p. 47-49, pl. 3, figs. 4, 4a, b), on the basis of their bifoliate fistuliporoid nature (well-developed lunaria, circular zooecial cross-section and separated zooecia with ample interzooecial space for development of vesicles). Ten apertures occur in a 2.5 mm distance. Zooecial diameter is about 0.25 mm. Lunaria can be determined. Scattered maculae are present, but are almost obliterated by the crystalline nature of preservation in specimen UNC 3913. In specimen UNC 3914, the maculae are 1 mm to 2 mm in maximum diameter and 3 mm to 4 mm apart.

Plate 1. Bored zoarial fragments of <u>Meekopora</u> cf. <u>M.</u> <u>clausa.</u> (1) Heavily bored side of zoarium, X3 1/2, showing boreholes at low angles to surface and areas of coalescence, UNC 3913. (2) View of end of branch, X3 1/2, illustrating bifoliate nature of branch and penetration of the tube system into the center of branch; UNC 3913. (3) Heavily bored side of zoarium, natural size; UNC 3913. (4) More sparsely bored side of zoarium, X 3 1/2, showing a few near-perpendicular holes near center of branch; UNC 3913. (5) Side view of sparsely bored zoarium, X3 1/2; UNC 3914. (6) End view of specimen shown in figure 5 above, X3 1/2, showing bifoliate nature of the frondose zoarium; UNC 3914.

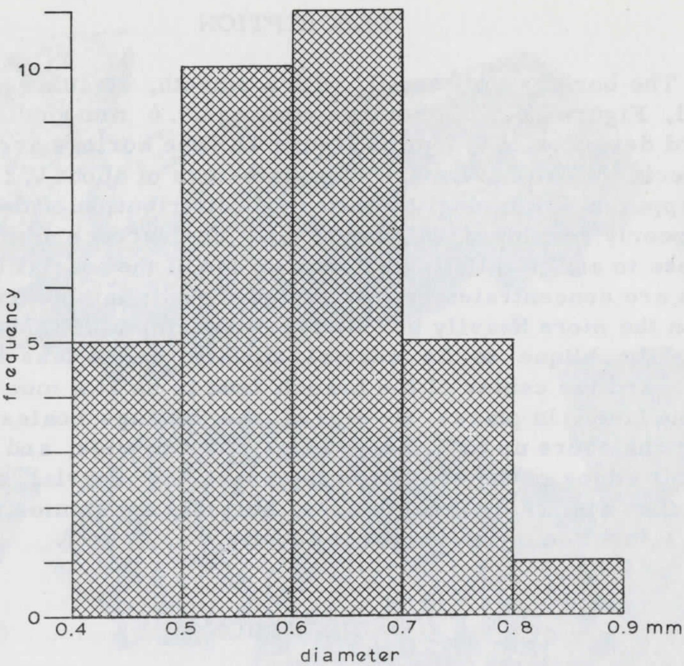

Figure 1. Histogram of diameter of boreholes in zoarial fragment of <u>Meekopora</u> cf. <u>M</u>. <u>clausa</u> (Ulrich).

The boreholes reported here are distinct from cavities produced by differential preservation, weathering and solution. The borings have a definite circular cross-section, constant diameter, smooth walls and a linear or smoothly curved path.

Organisms develop a boring habit in pursuit of food and/or shelter. Ectoprocts probably would not commonly be bored for food, because an animal that bores into an ectoproct colony with a substantial calcareous zoarium would probably expend as much or more energy to penetrate the skeleton than it could receive in nutrient energy from the ectoproct. Osburn (1921) reported that published accounts of the utilization of Recent ectoprocts as food by other marine organisms are rare, even though ectoprocts are abundant in today's marine waters. In fact, ingestion of ectoprocts, especially those with calcareous skeletons, is probably more accidental than intentional in most cases.

The nature of the borings in the specimens reported here indicates that the zoaria were dead and were lying on the sea floor when they were penetrated. There is no apparent structural healing of the skeletons, as might be expected if the zoaria had been bored while the polypides were alive and capable of secreting calcium carbonate. Also, the occurrence of most of the borings on one side of the bifoliate zoaria suggests that it is the side which was uppermost and consequently more easily accessible as the zoarium lay on the sea floor. It is therefore suggested that the organisms which bored into the zoaria were probably seeking shelter rather than food, and that there was no living relationship between the zoaria and the boring organisms.

Hecker (1965, p. 40, pl. 4, figs. 7-11) determined the relations between some ectoproct colonies and boring worms as probably commensalism (p. 40, pl. 4, figs. 7-9) and parasitism (p. 40, pl. 4, figs. 10, 11). Any worm that has a diameter greater than that of the zooecia and which bores into a zoarium must destroy the zooecia through which it passes. Therefore any living relation between zoaria and worms boring into the zoaria must be parasitism of the colony (or, exploitation of both the colony and individual polypides), whether or not the polypides of the zoaria are used as food. The ectoproct zoaria shown by Hecker (1965) in figures 9-11 show evidences of living relationships (parasitism). The ectoproct colony in figure 9 has what appears to be a plane of rejuvenation that coincides with the ends of a U-shaped tube, and the zoarium in figures 10 and 11 has a knobby, flangelike protuberance incorporating the outer end of the tube that penetrates the zoarium. Apparently the zooecia adjacent to the end of the tube were forced to build outward in order to complete with the food-gathering capacity of the worm, assuming that the boring worm was a filter-feeder. The zoaria illustrated by Hecker (1965) in figures 7 and 8 show no evidences of healing or abnormal structures associated with the borings, and it can therefore not be determined whether the worms bored into these zoaria while the colonies were yet alive or after the colonies had died.

Marine boring organisms are known from eight animal phyla, including Porifera, Ectoprocta, Phoronida, Mollusca, Sipunculida, Annelida, Arthropoda and Echinodermata (Menzies, 1957). Marine borers are also found among the algae and fungi.

Boring polychaetous annelids produce tubes which are most similar to those in the <u>Meekopora</u> zoaria. According to Boekschoten (1966, p. 354), the modern marine polychaetous annelid Polydora forms holes in shells which are parallel or oblique to the surface. Annelid tubes are about the same size as the tubes in the Meramec ectoproct, and they commonly occur in about the same density.

Phoronid borings have circular tube openings which are on the same order of magnitude as the borings reported here; therefore it is possible that phoronids were the organisms which bored into the <u>Meekopora</u> zoaria. The borings may be the work of sipunculids, but little is reported in the literature about boring sipunculids and they appear to be of minor importance.

Although clionid sponges create ramifying tubes and chambers of about the same size as the borings reported here, sponges produce a much higher percentage of chambers and communicate with the exterior by direct, rounded pores that are frequently arranged in symmetrical patterns. The borings of ectoprocts have a smaller diameter than that reported here, and they are mostly confined to the superficial parts of shells. The other boring organisms excavate areas of sufficiently different shape and size that they need not be considered in this report.

CONCLUSIONS

It is concluded that the borings in Meekopora cf. M. clausa are probably the result of boring polychaetous annelids (but possibly phoronids or, even less likely, sipunculids), because of their size, abundance and relation to the zoarial surface. The worms were most likely seeking shelter rather than food, because the ectoproct would not furnish enough food to repay the energy spent in boring. Boring probably occurred after the zoaria had toppled over on the sea floor, because most of the holes are located on one side of the zoaria.

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